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Augmented Reality System for Generating Operation Program of Automobile Assembly System

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1. Introduction

In recent years, the computer graphic technology has been growing dramatically with computer industry growth. In this exigent situation, the research of VR (Virtual Reality) and AR (Augmented Reality) technology which describe realistic scenes is performing actively (Daniel et al., 2007; Stephen et al., 2008; Bimber et al., 2008; Ong et al., 2003). Moreover, not only computer science companies but also many manufacturing companies have been studying about VR technology, because the global market requires a variety of product and shorter life cycle to fulfill the diverse demands of customers to survive in the turbulent and competitive market.

In the case of VR based digital manufacturing technologies, it can be used to analyze static and dynamic system behavior at all stages of manufacturing system configuration as an advantage (Günter et al., 2005; Park et al., 2008; Kim et al., 2008; Park et al., 2007; Park et al., 2006). To put it the other way around, the modeling work requires much expenses and efforts, because the whole system has to be modeled. Some manufacturing companies which realize the weaknesses of VR based digital manufacturing technologies have been studying AR technology.

AR means that the execution or planning ability of a real world is increased by the superimposition of virtual object on it. Basically, Augmented Reality is configured with three requisites as a real environment, markers and virtual objects (Fig. 1).

The ambitious goal of AR is to create the sensation that virtual objects are present in the real world. To achieve the effect, software combines VR elements with the real world. Obviously, AR is most effective when virtual elements are added in real time. Because of this, AR commonly involves augmenting 2D or 3D objects to a real-time digital video image (Stephen et al., 2008). AR technology can remarkably reduce the modeling work, because it uses the real environment to design and to plan manufacturing systems (Lee et al., 2008; Park et al., 2008).

AR technology is consisted basically of three modules which are image processing, tracking and rendering. The image processing module has to support the various types of the image data and can process the lots of image data. The image processing module sends the obtained image data to the tracking module. And the rendering module performs image

superimposition. Among these three modules, tracking and registration problem is one of the most fundamental challenges in AR research. The precise, fast, and robust tracking of the observer, as well as the real and virtual objects within the environment, is critical for convincing AR applications. Because of this reason, much research effort is spent to improve performance, precision and robustness of tracking. Besides tracking, real-time rendering is also basic element for augmented reality. Since AR mainly concentrates on superimposing the real environment with graphical elements, fast and realistic rendering methods play an important role (Bimber et al., 2008).

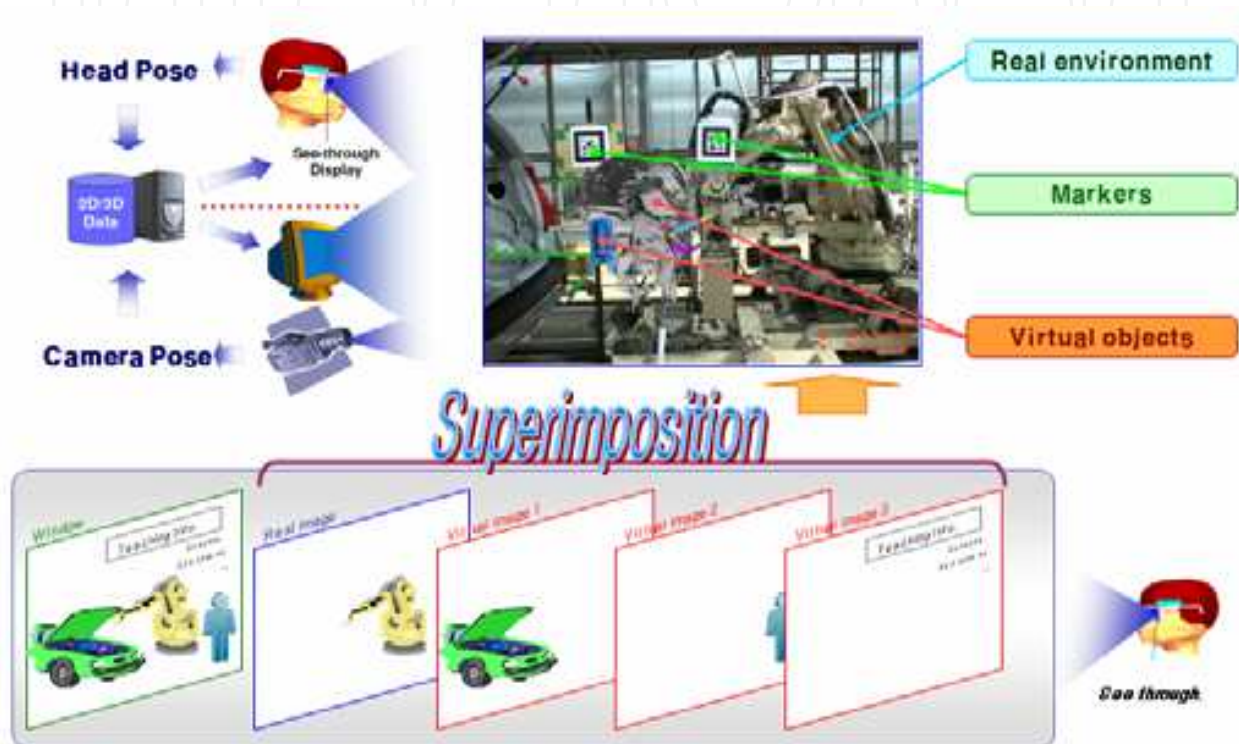


Fig. 1. Configuration of Augmented Reality System

To develop an AR system for manufacturing application, the design specification is derived out from the analysis of manufacturing problem and application environment. Based on the specification, the system architecture is designed. The necessary function modules are developed from the architecture. For the convenience of users, the application modules are also developed. To implement an AR system, the developed modules are integrated.

Through the integration of the previous developed modules, the AR-system was implemented. These user friendly UI and the functions support a planner or an operator to carry out the results easily. For proving the functionality of the developed AR-system, it is applied to a practical problem, i.e. placing spare tire on a mount hole in trunk. For this purpose, A test bed with 1/ 5 scale of a real system was realized. For solving the inserting problem with the AR-system and for carrying out the inserting process, the real system components and the virtual objects were developed and modeled. With the previous mentioned installation, a programmer generate the robot program for the inserting process with teach pendent in front of a monitor, i.e. the programmer carry out the programming process without seeing the real system.

2. Design of augmented reality software for manufacturing system

2.1 Design specification of the AR-System

The software development activities of AR for the manufacturing system consist of requirements analysis, specification, software design, implementation, testing and maintenance. These processes were performed recursively with correction of each step. In the requirements analysis step, the general requirements were gained from the client and the analysis of the scope of the development was determined clearly. The analysis document of requirements includes the flow chart of overall tasks, the systematical analysis information of functions, activities and data.

The concise software development scope is as follow.

1. The user selects the camera devices which are connected to computer by the device enumeration dialog box.
2. The user inputs the each number and total count of markers.
3. The 3D objects (.wrl) are loaded to use for the parts of the manufacturing system.
4. After markers and virtual objects setting, the display device shows superimposition of real-time images.
5. The translation, rotation and scale data of each virtual object can be controlled by the user.
6. The clipping plane for collision detection can be created and also can be controlled by the user.
7. The visible and invisible functions for the images and virtual objects are able to operate.
8. The marker tracking start and stop functions can be used during the software activity.
9. The user can confirm the information about program activation by the message boxes.
10. The information of each marker and each virtual object data can be removed by the user.

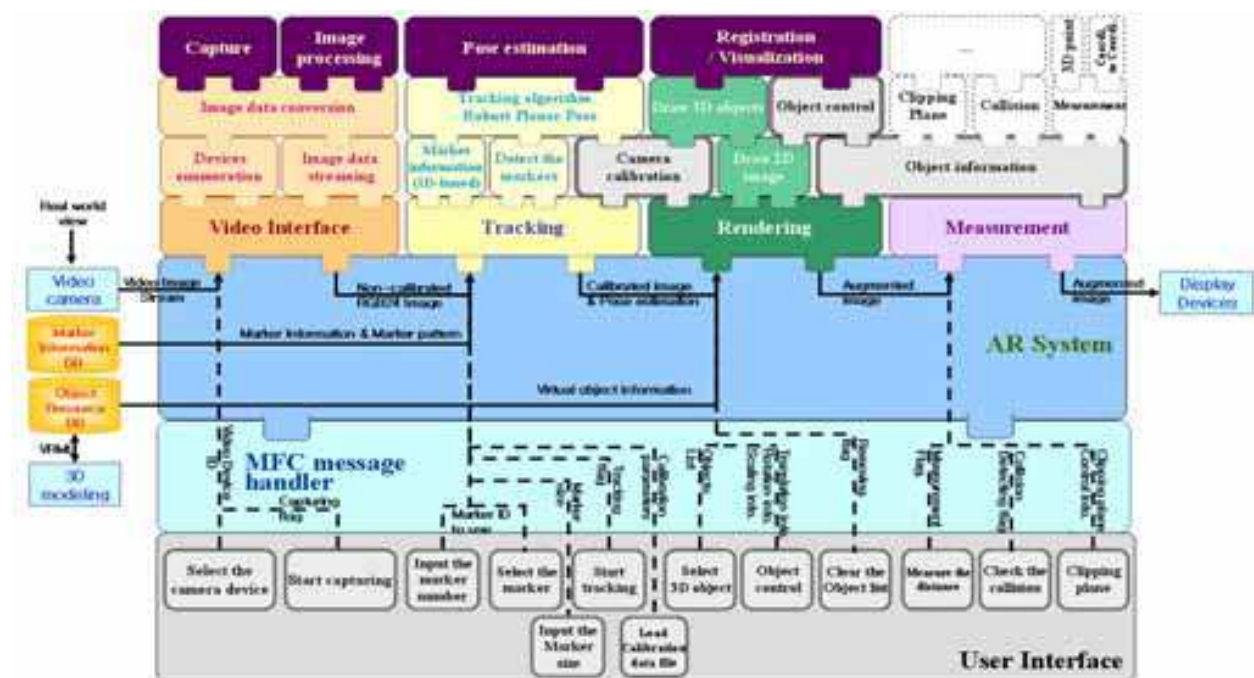


Fig. 2. Architecture of AR System

Based on the specification document of requirements analysis and the three basic modules which were introduced at chapter one, the auxiliary functions can be supplemented for

manufacturing environments. In order to overcome dim environment condition and the weakness of the virtual object, the convenient functions which are clipping planes for collision detection and threshold control panel for the dim condition. And these functions support the user to work efficiently. Fig. 2 illustrates the architecture of AR system. And the core development tool is MFC (Microsoft Function Class) based on C++.

The image data from a camera device is processed in video interface for the marker tracking. The video interface converts the video image stream into non-calibrated BGR24 image. Then the tracking function calculates continuously coordinate data of the markers to detect location of each marker. The basic coordinate system for positioning virtual objects is established through the matching procedure between the information of the marker database and the input data of the user interface. The rendering function performs generating and removing of virtual objects with calculated coordinate data. Also, the coordinate transform of virtual objects is executed by using three translations data, three rotations data and three scales data.

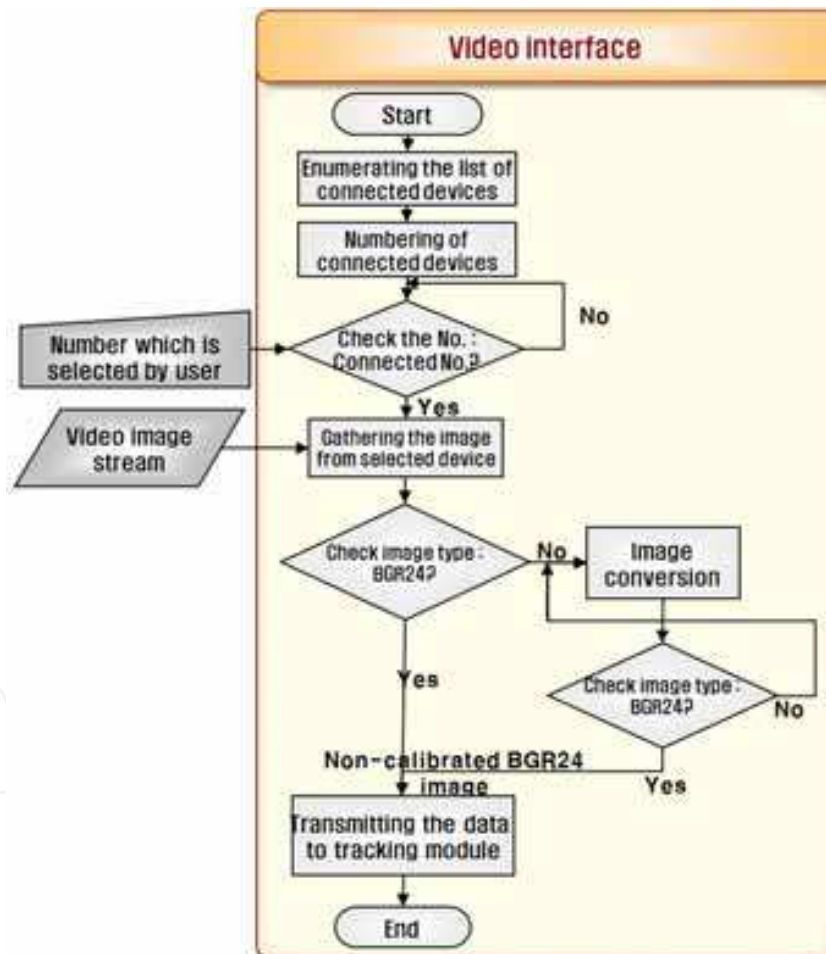


Fig. 3. Gathering the image data from connected devices

The Video Interface module executes to obtain images from external devices such as video camera etc. If the cameras are connected to the computer from the outside such as USB webcam, IEEE 1394 camcorder etc., Video Interface module enumerates the connected devices. After numbering work for each camera, the Video Interface module compare the number of

connected devices with the number of selected device that a operator will use. If the numbers are exactly matched, the Video Interface module gathers the image from selected device to use for superimposing (Fig. 3).

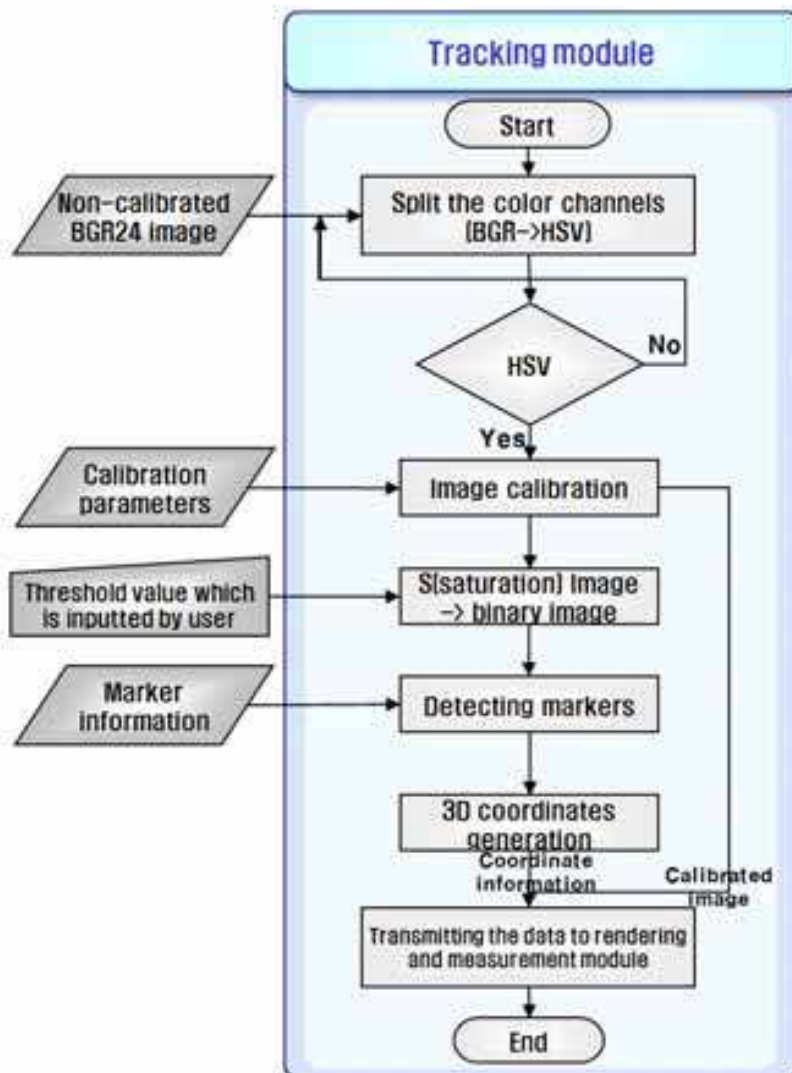


Fig. 4. 3D coordinates generation after marker detection

For establishment of coordinate system, the tracking module is used. In order to calibrate the BGR24 image that is from the Video Interface module, The Tracking module splits the color channels to HSV type. After that, the HSV image will be calibrated. The calibrated image will be changed to the binary image in order to generate 3D coordinate information (Fig. 4).

The Rendering module is to carry out the calculation process for displaying images. This module generate the world coordinate system and set the camera view position. In order to superimpose the 2D image and the 3D objects local coordinate based on marker position and world coordinate will be synchronized. And each image such as 2D image and 3D objects will be drew on the same display plane. In case of the binary image, it will be used to change binary value to overcome dim condition of manufacturing area (Fig. 5).

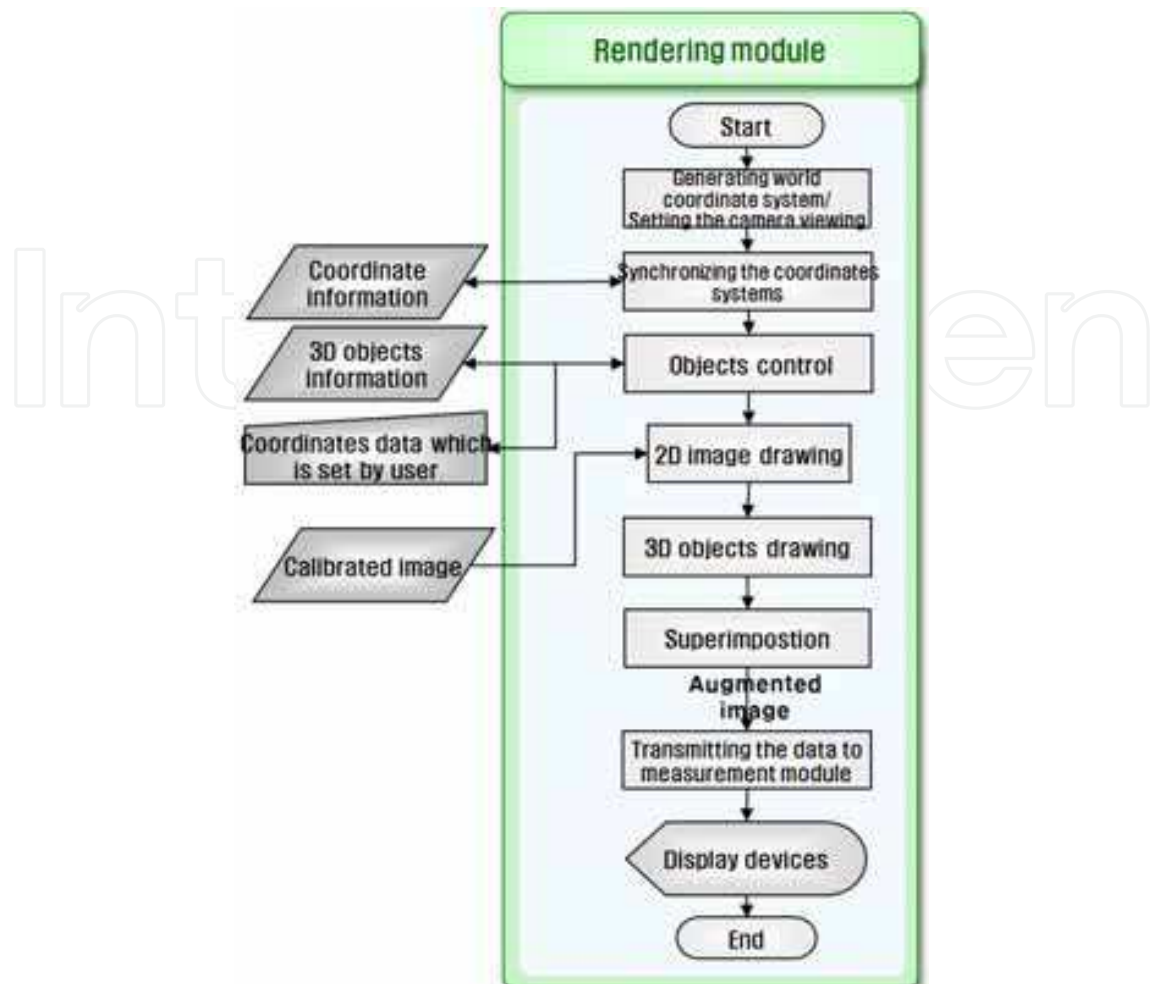


Fig. 5. Superimposing the 3D objects on the 2D image

2.2 The configuration of the user interface

The user interface designed based on basic functional analysis of whole system as shown in Fig. 6.

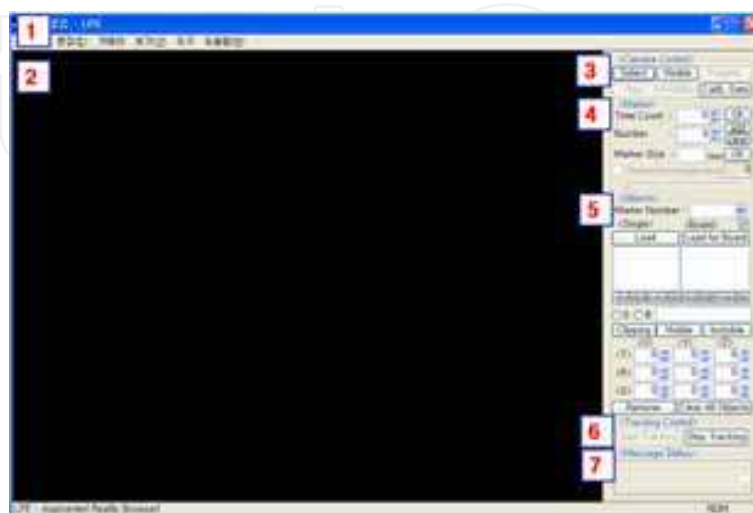


Fig. 6. Layout of user interface

1. The menu bar
2. The display plane for the render scene
3. The camera device controlling panel
4. The marker information setting panel
5. The virtual object controlling panel
6. The tracking function panel (start/ stop)
7. The message enumerating panel to check program state

The menu bar consists of the functions which are performed from the right side panels. The display plane is the drawing board for superimposition of scenes and it draws 3D objects and 2D images from the camera. The user can confirm the list of connected camera devices by using the camera control panel and can change the camera properties easily. The marker information setting panel is used to input the information of the marker such as the size of the marker, the number of the marker, the total count of the markers to use and so on. And it is also used to control the marker information. The virtual object controlling panel is used to load the 3D objects for rendering and to control. The tracking function panel is used to control start and stop for the position tracking function. The message enumerating panel is helpful for user’s activities to check program state.

3. Implementation of augmented reality system

3.1 Obtainment and conversion of real-time image data

Precision and accuracy of target tracking depend on the image resolution of the camera device. USB Web Camera which has low resolution is used generally for experiment at a large number of laboratories. However, ordinary manufacturing system requires the tasks with high precision and accuracy. Because of this reason, the digital video camcorder that is connected to computer through the IEEE 1394 interface was used. OpenCV is the prevalent open source vision library suitable for computer vision applications. Fig. 7 depicts whole image processing step structure.

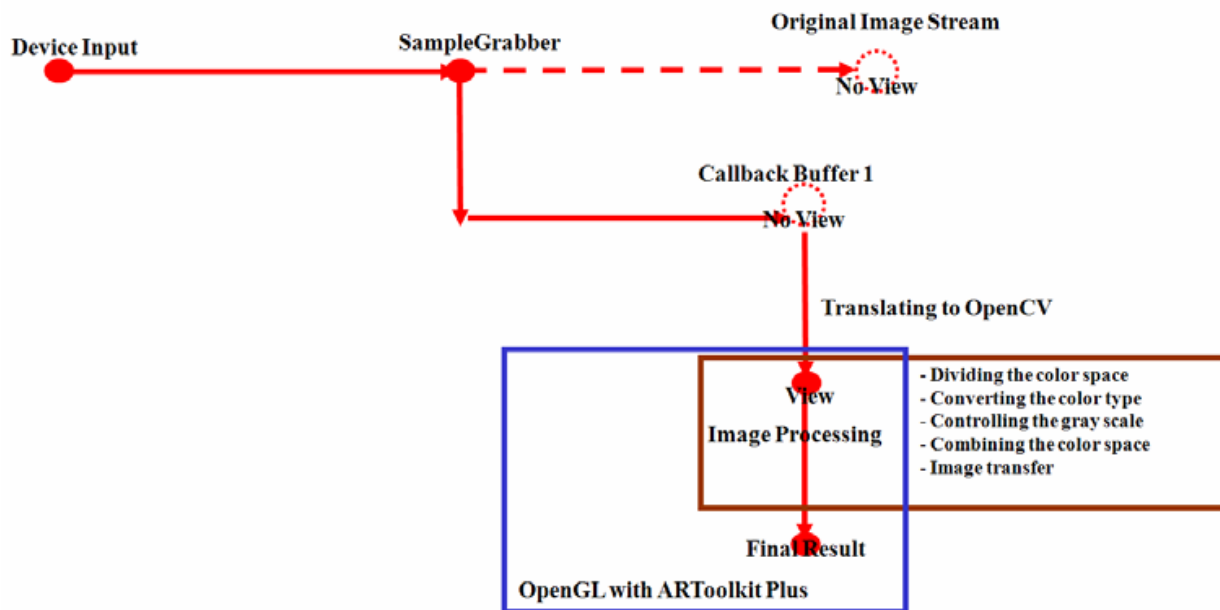


Fig. 7. Image obtaining and conversion steps

However OpenCV does not support digital video image type. To solve this problem, high resolution buffer is obtained by using Microsoft DirectShow technology in this research. The rapid image processing is possible by using various filters. It is a representative advantage of DirectShow. Also well-composed filters are figured out readily through the GraphEdit which is the utility of DirectShow. Based on DirectShow, device filter, preview filter, digital video supporting filter, SampleGrabber filter and Video Renderer filter are used to gather RGB24 image data. Moreover the obtained image buffer is converted into IplImage structure of OpenCV. This technique has the ability to access readily and offers the efficient method which converts RGB24 image data into different image type. The last image type is BGR24.

3.2 Position tracking of target markers

The position tracking of the target marker is the core technology that is determinant for precision and accuracy of AR technology. For tracking target markers, many methods, such as mechanic, magnetic, and optical are examined. Here, the optical method is widespread due to its high precision among the tracking methods. The camera device reads real-time video streams to generate see-through effects on the display equipment. Then edge detection is performed by thresholding with constant value. After this step, the information of detected marker is used to track the local coordinate in the centre of the marker by using matrix calculation.

There are some pose estimation algorithms as the robust planar pose algorithm, the fast pose estimation algorithm, and so on. These algorithms were ported to C++ added to the open source libraries as ARToolkit, ARToolkitPlus, ARTag, and so on (Daniel et al., 2007; Stephen et al., 2008; Bimber et al., 2008; Gerald et al., 2006). In order to be robust system, ARToolkitPlus tracking function that includes improved pose estimation quality with less jitter and improved robustness was used to track coordinate system. The important function for using is `rppGetTransMat()` (Daniel et al., 2007). This function performs matrix parameters translating to transmit the coordinate data to the rendering module. For this achievement, codes of the matrix parameters translating function and of the tracking function were generated.

The virtual object can be superimposition on the real scene by using each ID-based single marker. Moreover the multi-marker which has one local coordinate system can be used to track. Every single marker size was set 100mm and the user can change the marker size as required at the user interface. The multi-marker size can be changed in the designated data file.

3.3 Implementation of virtual objects loading and superimposition of scenes

The superimposition of scenes is performed by using the obtaining image data, the tracking positions and the virtual objects. The system requirement of the hardware is prime concern to draw the scenes into viewing rectangle of the user interface. Therefore, the overall specification of the hardware as a graphic device, CPU and memory devices have to be high. The high specification of the hardware prevents jitter and lag of the superimposition scenes (Rhee et al., 2007). Also the VRML (Virtual Reality Modeling Language) object files decrease the software overhead and improve the problems of jitter and lag status. All things considered, the object control panel can load text files (.txt) which include the coordinate information of the virtual object based on rearrangement coordinate matrices. And the data

structure including the two-dimensional array was designed for each object rendering on the marker. The data structure has the information of each marker number, visible/ invisible, object number and translation-rotation-scale of each object as shown in Fig. 8. These processes are performed by using OpenGL open source graphic library.

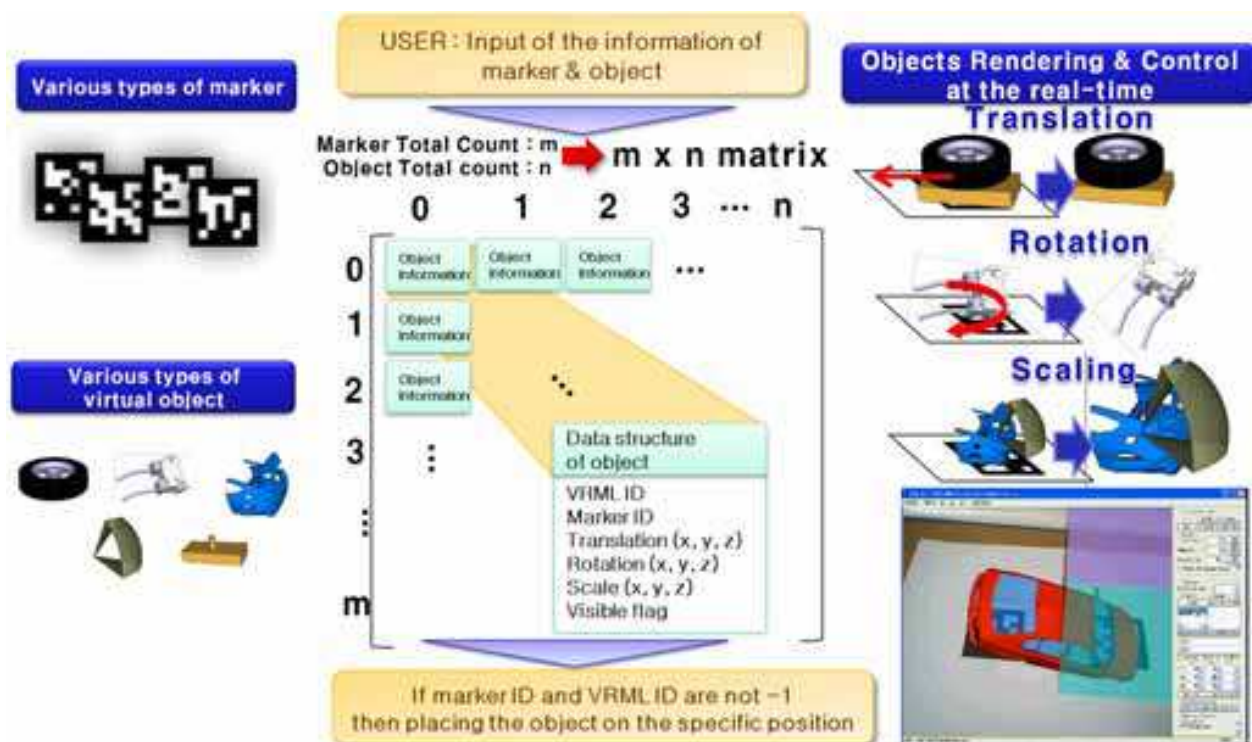


Fig. 8. Matching and control structure of the 3D object information

This information can be controlled through the object control panel. The translation unit value of the virtual object is 1mm and the rotation unit value of the virtual object is 1° . In the case of the scaling, required input value through the user interface is 100 when the side length of the square marker is 100mm. If the side length of the square marker is 40mm, the input value must be 40 to satisfy 1:1 scale between the viewing object and the modeling object. With the information matrix in Rendering module, the matching of the marker and the object and the manipulation of objects are done.

3.4 Implementation of auxiliary tools

The clipping planes can be generated to check the collision between the virtual objects and to ensure the inside area of the virtual objects. The `glClipPlane()` function of OpenGL was used to generate clipping planes. Therefore, the user can generate 6 planes and can use them at the same time. The normal vector of the clipping plane is derived from the equation of plane to achieve same effect as object controlling. The equation of plane is derived by using one known normal vector and one known point in the three axes generally. However, the normal vector of the clipping plane is derived by using one known point $O(0, 0, 0)$ and three angles which were inputted by the user as shown in Fig. 9 and Eq. (1). And the point $O(0, 0, 0)$ is always used to calculate the equation as the known point.

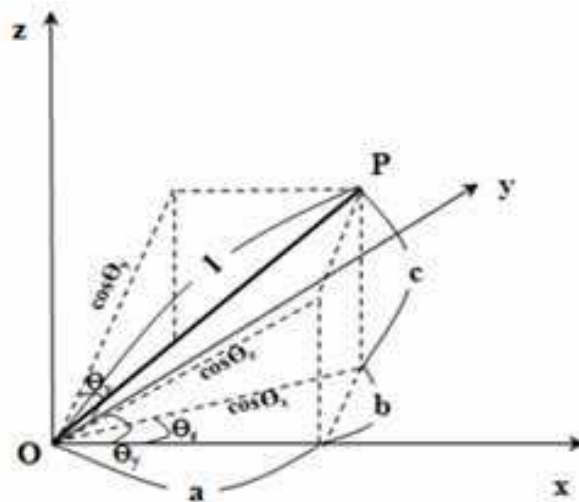


Fig. 9. Relation of known three angles and the normal vector of the plane

$$\begin{aligned}
 a &= \cos(\theta_y) \cos(\theta_z) \\
 b &= \cos(\theta_x) \sin(\theta_z) \\
 c &= \cos(\theta_z) \sin(\theta_y)
 \end{aligned}
 \tag{1}$$

where, a = vector element of x direction, b = vector element of y direction and c = vector element of z direction.

$$\theta_x, \theta_y, \theta_z = \text{three known angles}$$

Through the derived normal vector decides the direction of the plane and the plane can be rotated between -180° and 180° by the user's activity. In this case, both the translation and scaling were not considered.

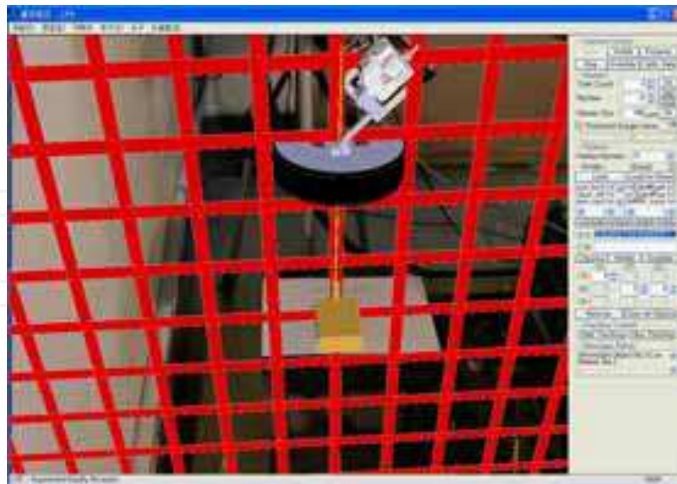


Fig. 10. Using the clipping plane

The generated clipping plane does not have visualization feature. Because of this problem, there is the difficulty to recognize the location of the clipping plane in the virtual space. To solve this problem, the virtual object of the grid plane is created basically and it is matched with the clipping plane at the same time as shown in Fig. 10.

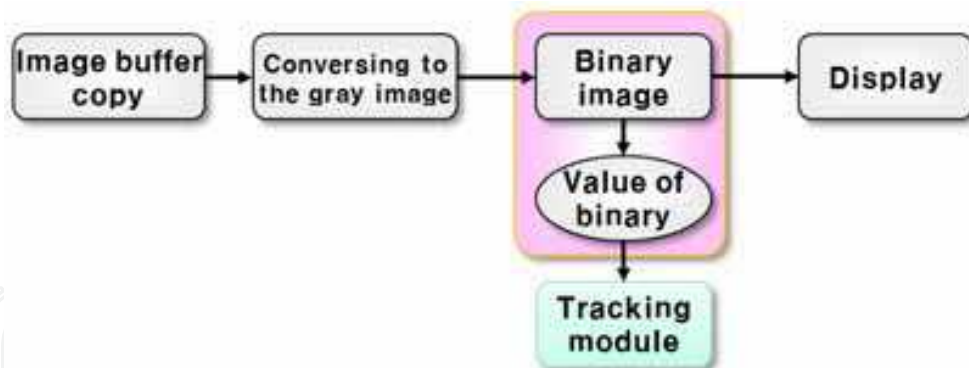


Fig. 11. Binary image value control steps

The manufacturing field has poor light condition. For this reason, the optical marker cannot be recognized easily. To supplement this handicap, threshold value is controlled through the panel. The function of controlling threshold value returns selected pixel value of the binary image from 0 to 255. To control the threshold value, the functions of OpenCV are added as a cvThreshold.13 Binary image value control steps is shown in Fig. 11.

4. Configuration of manufacturing system based on augmented reality

4.1 Component modeling work for system configuration

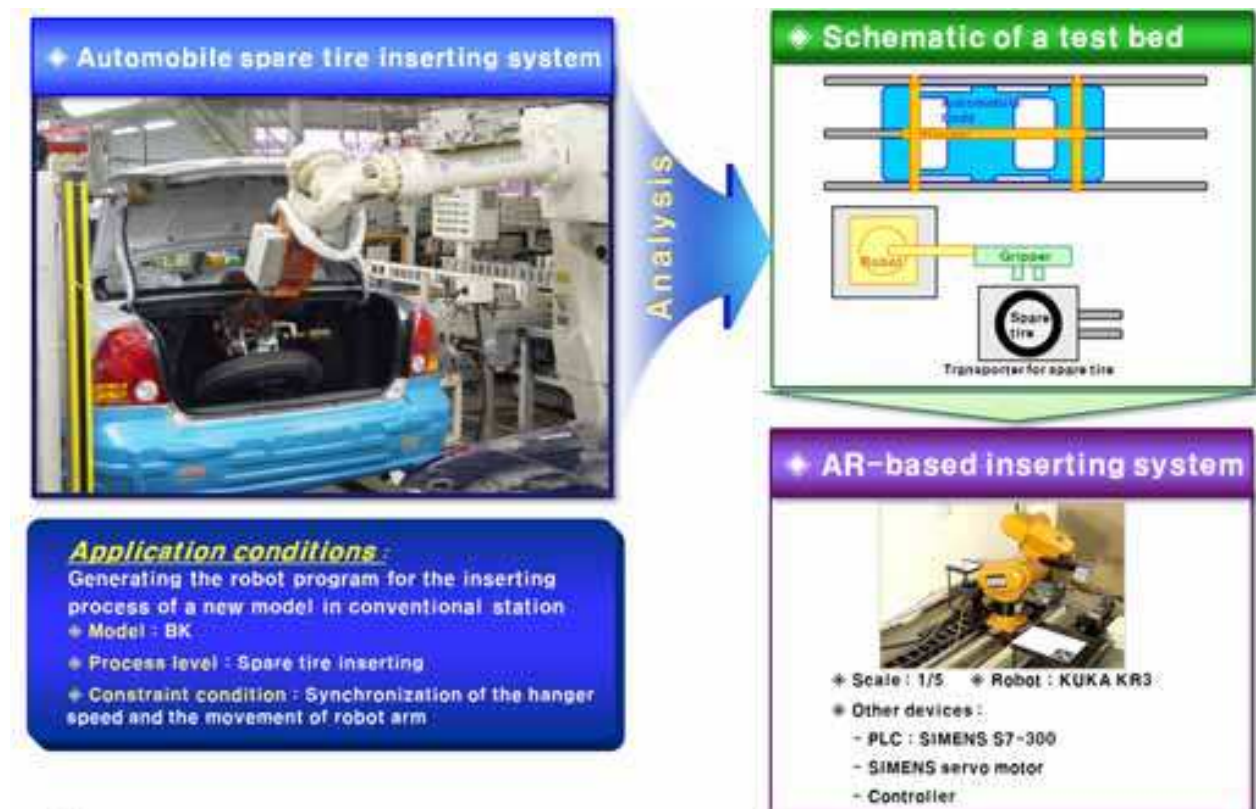


Fig. 12. Development of AR-based assembly system

Through the integration of the previous developed modules, the AR system was implemented. For proving the functionality of the developed AR system, it is applied to a practical problem, i.e. placing spare tire on a mount hole in trunk. The task of AR system is

to generate the robot program of this inserting process for a new model in the conventional station. For this purpose, a test bed with 1/5 scale of a real system was realized (Fig. 12).

Three markers and cameras were installed in the appropriate location (Fig. 13). In order to increase work efficiency, it is better to set three display devices which are connected with one PC because each monitor can display the images of each camera. In this case the operator does not need to change each view of the scene.

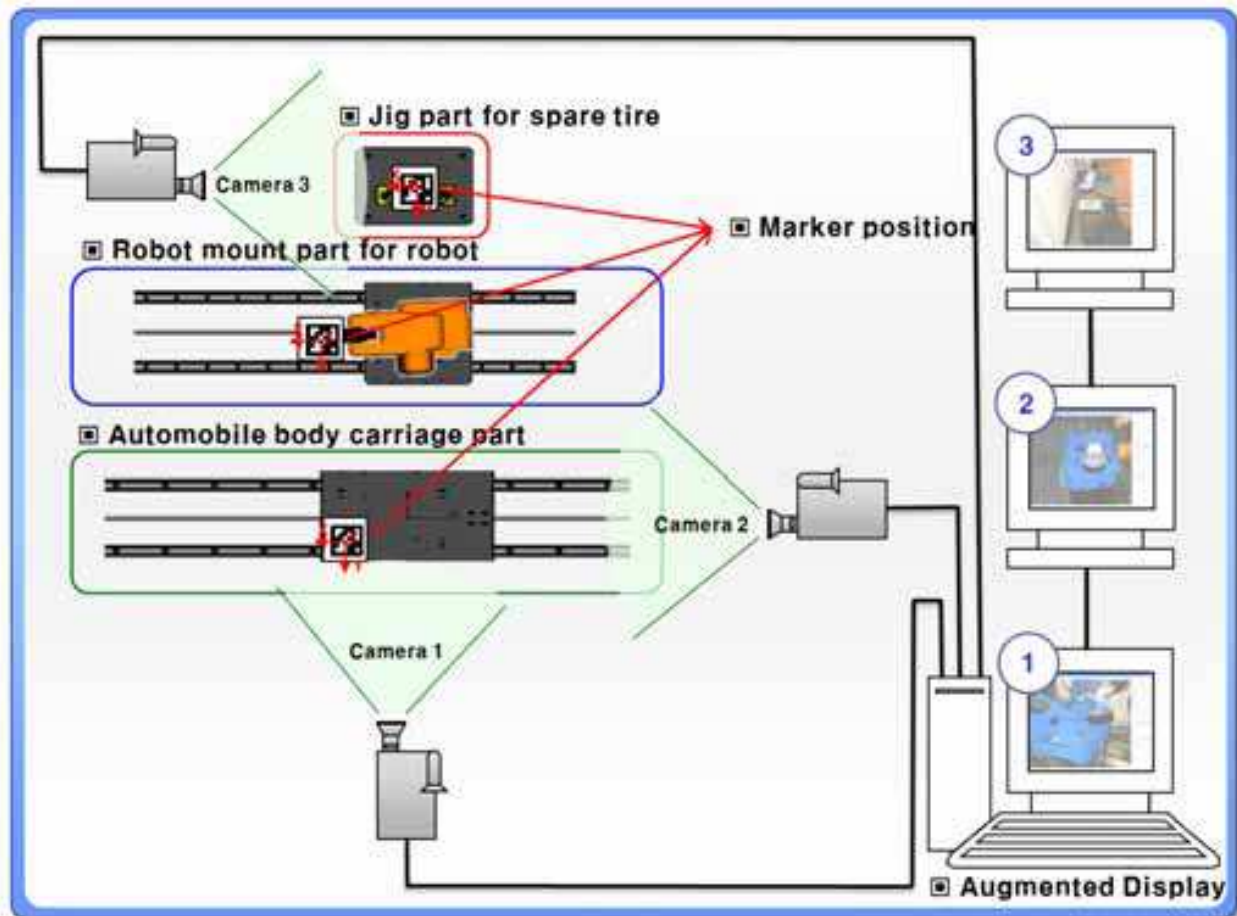


Fig. 13. Installation of cameras for the AR-based inserting system

The developed AR system is applied to the reconfiguration process of the automobile cockpit module assembly system which is the test bed for the real manufacturing system (Park et al., 2008). The target system is the automobile spare tire inserting system. Almost new components have to be remodeled. However, the air finger, the connecting part of the robot and the ball screw are changed partial dimension except overall outer shape. In this case, the existing facility of the test bed is used as it is. The gripper and air finger which perform assembly work, the automobile body for transfer, and the jig/ fixture for the automobile body, the encoder and coupling for the synchronous velocity are continuous parts of the virtual object structurally. And these parts perform similar work. Therefore, the each 3D model of them is generated. And the spare tire, the mount for the robot and the jig/ fixture of the spare tire are modeled individually. Moreover, the auxiliary tools for collision-free between the peripheral unit and for accurate assembly work were modeled. The centre datum line was generated individually to match between the assembly part of

the automobile body and the spare tire. And the approach path was set and was modeled to avoid collision between the robot and the automobile trunk. The operator is able to perform generating of the robot operation program precisely by using these auxiliary tools. Fig. 14 shows the 3D models for system configuration.

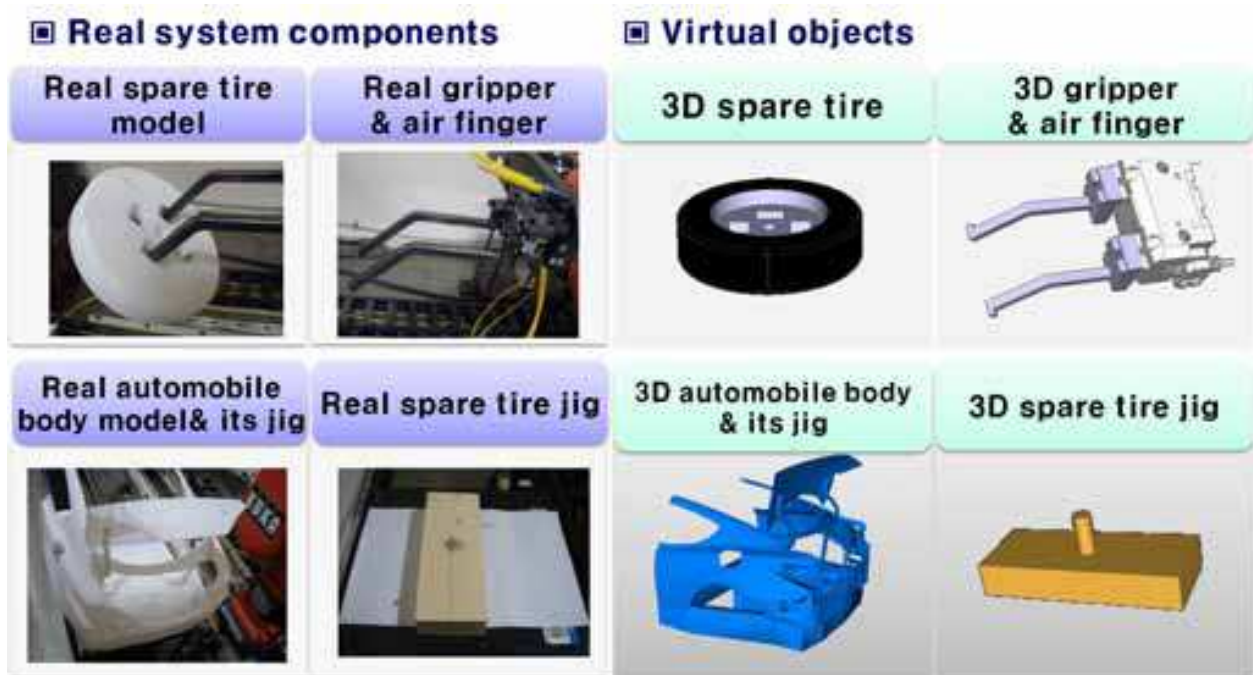


Fig. 14. Preparation of the system components for carrying out the inserting process

4.2 Setting coordinate systems based on markers

Fig. 15 illustrates the generated coordinate systems for configuration of the spare tire inserting system. To perform superimposition of the generated 3D models, the coordinate system for positioning virtual objects has to be established. The Generated 3D models are divided into two groups.

The first group has dynamic motion and the second group does not have movement. The spare tire, the gripper and air finger which perform assembly work require independent one coordinate system (coordinate system No.1). Also the centre datum line of the spare tire for assembling serviceability used the coordinate system No.1. The coordinate system No.1 has to be mounted on the end of the robot gripper. Moreover, the system should be seen in every direction due to free movement of the robot. Therefore, the coordinate system No. 1 which has several markers was manufactured in the structure of a box type. And the automobile body and its jig/ fixture on the carriage part require independent one coordinate system (coordinate system No. 2), because the carriage plate influences to the automobile body and its jig/ fixture. The centre datum line of the automobile body and the path of assembly work used the coordinate system No. 2. In addition, one marker which considers the position of the camera device was established. The encoder, the coupling, the mount for the robot and the jig/ fixture of the spare tire are fixed components and they have collision-free during assembly work. So these components use one coordinate system (coordinate system No. 3).

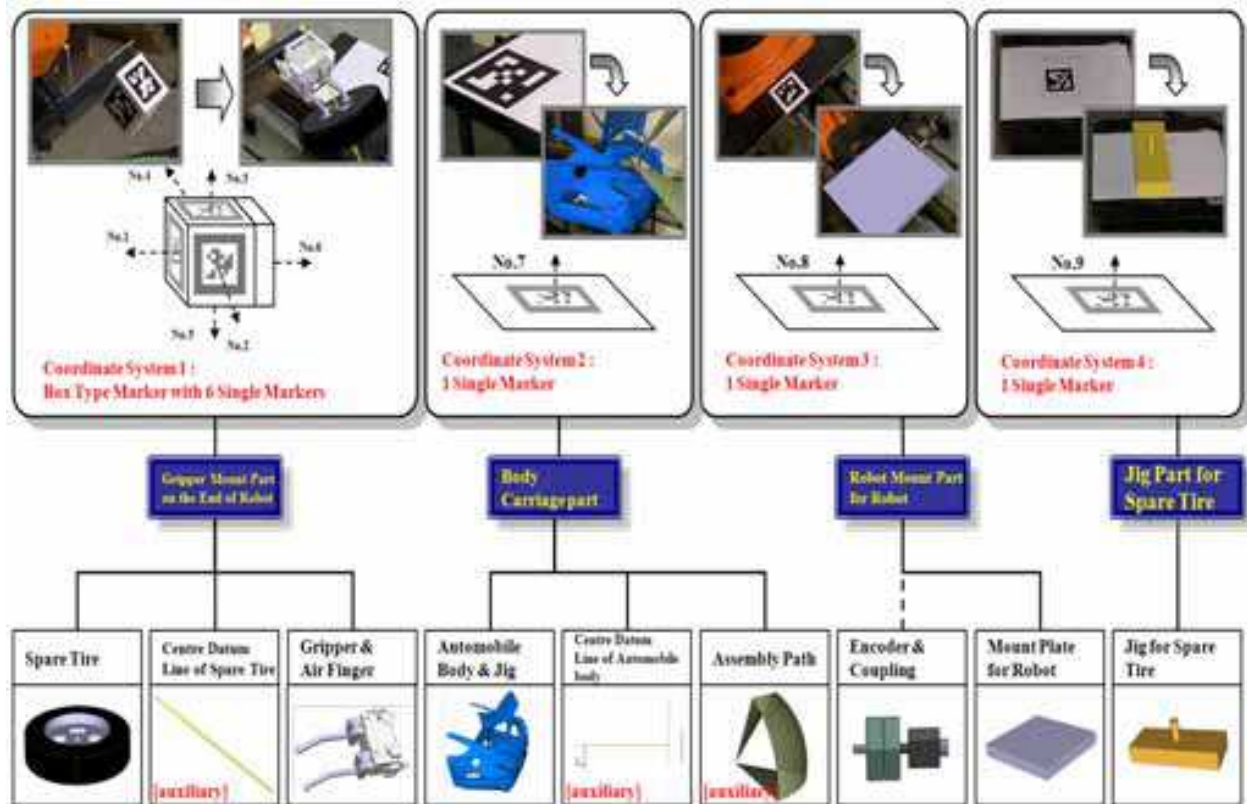


Fig. 15. Design of the markers for establishing the coordinate systems

4.3 Generating operation program for spare tire inserting system

The test bed of the automobile spare tire inserting system is configured as a 5X-reduced scale. The operator generates the robot operation program with two cameras. One camera is set at the side of the test bed and the other is set at the behind of the test bed.

The clipping plane is generated for the alignment of the inserting objects, i.e. spare tire and mounting hole and for calculating the moving distance of the spare tire. For the collision free inserting of spare tire, the auxiliary model guides the inserting path. With the previous mentioned installation, a programmer generate the robot program for the inserting process with teach pendent in front of a monitor, i.e. the programmer carry out the programming process without seeing the real system. Through down loading the generated robot program, the correctness of it can be proven. The completeness of the generated operation program was proven by applying it to the conventional assembly station. The boundary conditions, such as the position tolerance range within 1~5 mm, were fulfilled. Fig. 16 illustrates the generating operation program of the automobile spare tire inserting system by using AR.

5. Conclusion

The AR system which can be used at the manufacturing system was developed based on general software development method. The fundamental functions as the video interface, the tracking and rendering were implemented. And the manufacturing field condition-oriented auxiliary functions were added.

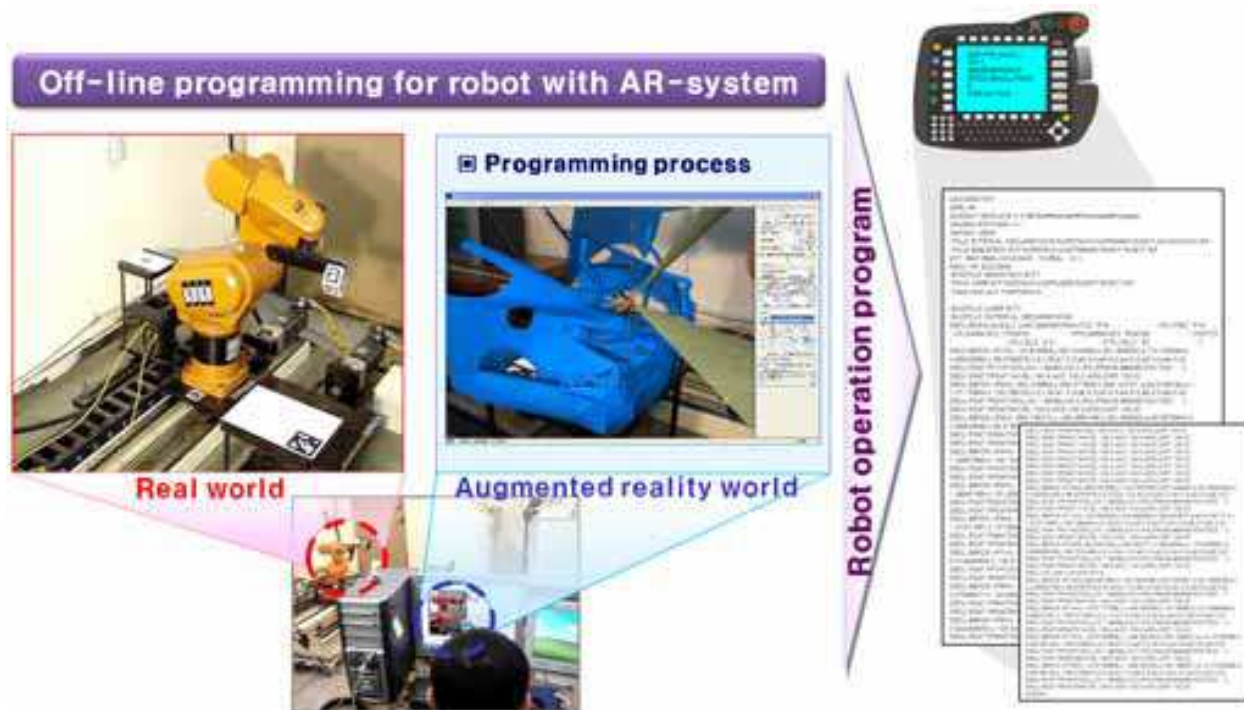


Fig. 16. Generating a robot program for operating the insert processes

The function of generating clipping plane and controlling for precision and accurate work was used effectively during generating robot operation program. And the threshold value control function has similar effectiveness. These results attest functionality of the developed AR system which has high usability when the manufacturing system configuration is performed.

The benefits of the developed AR system read as follow:

- Generating an operation program of a manufacturing system for new model without prototypes and in a conventional manufacturing system.
- Modification of the conventional manufacturing system for manufacturing new models in advance.
- Reduction of ramp-up time dramatically.

The module for measuring the distance between virtual objects in virtual world will be developed. Moreover the module for simulating dynamic behaviors of virtual objects will be developed. And for applying to the mass production system, CCD camera should be applied to acquire images. In the developed AR system, digital video camcorder is used.

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