Research on Operating Simulation System for Tower Crane Based on Virtual Reality

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Abstract. Virtual reality technology has become a hot research spot and been widely used in many industries such as education, military, entertainment and medical science. This paper analyses some key technologies of virtual reality application on tower crane operating simulation system with tower crane operating characteristics, including the virtual semi-physical model construction of tower cranes based on three-dimensional optical measurement, scene realization and multi-channel screen display of tower crane operation high above the ground, virtual dynamics simulation and motion trajectory planning of tower body and wire rope and lifting weight in case of multi-load, virtual assembly for installation and uprise and destruction of tower crane, expert system of examination simulation and fault reproduce and so on. The paper also describes the difficulties in implementation and study process compared with the bridge (door) crane virtual operating system which has been put into application. Finally the next research is proposed aimed at current needs of safe operation of tower cranes.

Keywords: tower crane, virtual reality, three-dimensional optical measurement, virtual assembly, expert system.

1 Introduction

It is dangerous during the mount, use and inspection of cranes, therefore the administrations declare the operators of cranes must be tested and certificated by the safety education and skill training. To recall the requirement, the related administrations have formulated the content and requirement about examination of the safety education and skill training. Now besides the practical training, most certification organisms have founded a set of effective, objective and intelligent examination method to teach and test the knowledge of the safety and operation. To remedy the lack of practical training, some organisms train the operators in the leased crane. But this method costs a lot and gets unsatisfactory results. Under this condition, the administration allows to train and test the operators on the simulated devices of cranes, and the certificated organisms in charge of the drivers and directors should have the simulated crane training system which can simulate the movement or action of the rotation-mechanism or the luffing–mechanism [1]. To solve the problem, a lot of

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enterprises work hard and try to design and develop such simulators. At the same time, the WHBTS have founded a research team and developed a set of simulation system for the crane operators training and test with the cooperation of WHUT[2][3]. This system has solved a lot of problems of simulated training and test, and been used to examine the operators.

During the development of the simulation system, the research team investigated the present simulated system of tower crane, most of which have some shortcomings. Some don't have satisfied training and test results, and others can not provide the best realistic vision of tower crane so that they can't simulate the work condition and movement of tower crane naturally.

Tower crane work high above the ground. And its movement is different from that of the bridge crane. Tower crane can hoist, slew, luff, while bridge crane can only do the traverse movement by move the carts and hook. On the other hand, besides day-to-day operations, operation of tower crane includes the setup, jacking and disassembly. All the process need to be simulated.

This article analyses the key technology of virtual simulation of tower crane , including modeling of tower crane based on optical three dimensional measurement, multi-channel display system of tower cranes in visual realization, building the dynamics formula of the moving structure, realizing the visual working processes of self-climbing, hoisting, slewing. With the word of the developing team, the system has modeled the base section, tower section, operator cab, tower head, counter jib assembly, driving bogie, driven bogie, tower crane anchor, hook height limiter, slewing limiter, trolley travel limiter, hoist moment limiter, overload limiter and anemometer. And the system realizes the visual assembly, fault and operation.

2 Composition of the Simulated Operation System of Tower Crane

Based on the construction site of WuHan saloon, the simulation system of tower crane has modeled the TC5610 tower crane and can be used to train and test the operators. The system is composed of four main models, such as vision system, control system, visual fault and mistake system, training and estimating system. The operator can control the visual tower crane by the signal gathering system. After the vision system gets the process of control, it simulates the movement of the operation right now. Meanwhile, the expert system can estimate the operation with the gathered signal. With the cooperation of the four models, the system can provide the real visual training condition and simulate the assembly, self-climbing, dismount and setup some faults during the design and manufacture.

The control system is the hardware part, including the database interface and Human-machine interaction. It has the panel and seat, and is designed based on the practical operator cab. The operators can control the visual tower crane in VR of tower crane when they operate the panel.

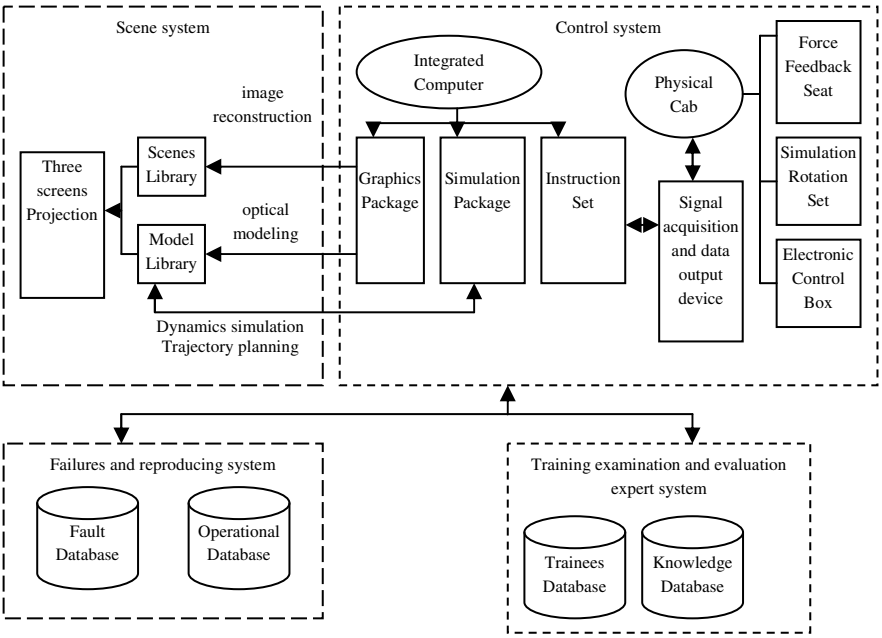

Fig. 1. System composition framework

3 The Virtual Semi-physical Model Construction of Tower Cranes Based on Three-Dimensional Optical Measurement

The first problem to be solved is to create a virtual environment including three-dimensional model, three-dimensional sounds, etc. In these elements, the information received through sense of sight is the largest, and the reaction is also the most sensitive. So it is the most important to create a reasonable and realistic 3D models which can be interactively displayed real-time and dynamically at the same time.

Building a complicated three-dimensional model has been always restricting the development of virtual reality technology seriously. The process of generating accurate three-dimensional model is also very difficult from what happened twenty years ago, even though the graphics rendering technology to achieve realism has gone forward in stride [4]. After years of developing virtual reality modeling technology, but the modeling methods are time-consuming and laborious all time such as feature-based modeling, parametric modeling, etc.[9] These automated modeling methods validate that real-world geometry is extremely complex. It is still required that manually drawing most of the models, and hiring high-level professionals, of which the cost is quite amazing. For example, it will spent up to $ 25 million labor costs on achieving the three-dimensional model scenes and variable special effects in the movie "Tanks Titanic", the money of which is enough to produce a same size true boat.

It is general that using all kinds of CAD modeling software such as 3D Max, SolidWorks, MultiGen Creator to carry out the three-dimensional model of tower

cranes, and then simulating the scene by means of virtual simulation software such as Vega, Virtools or development tool kit OSG or other simulation in our country.[5]complex modeling of tower cranes needs to simplify various components and devices and developers will still spend a lot of time. If modeling costs is too high, it is not as good as purchasing physical objects for teaching training and examination. If the difference between scene and reality is too big, then it will lose the effectiveness of training because the participants in the actual scene of the experience will feel completely different.

The technology of three-dimensional laser scanning provides a number of conditions to simplify the model construction process. Semi-physical modeling based on three-dimensional optical measurement can significantly shorten the model workload and truly reflect the actual model size, surface texture and reduce development time largely.

TC5610 (QTZ63) is the most widely used tower cranes, which adopts horizontal tower, trolley jib, high level slewing self-raising technology and is a multipurpose tower crane. The true tower crane simulated in this paper is made by Hubei Jianghan Construction Machinery Co.Ltd, and the type is TC5610-6,which has 56m maximum jib length ,and attached maximum raising height is 141m, load moment is 630kN.m, maximum lifting capacity is 6t, maximum lifting torque 92.2t.m.This kind of tower has been produced for many years, and is very common in the market. So it is completely unnecessary to make accurate three-dimensional modeling according to 2D CAD drawings. It can be realized by only measuring the physical crane. This project uses the ATOS Compact Scan 2M optical measurement system of GOM for TC5610 tower crane model.

ATOS system includes measuring head, stereo cameras, fringe projection, controller and bracket, as well as calibration disk for high-precision calibration and software for the Windows operating system[6].ATOS system can fast measure object with point group and high-resolution using optical principle, which gets 2 millions point data once. The same several measurements of objects can be integrated into a Project(collection of multiple measurements),and the point cloud data, the cross section point cloud data, the triangular mesh surface data or characteristic line data can be captured and output. It is easily to measure the object through a fixed tripod, measurement error is monitored by the computer and the measurement results is data analysed and integrated. It also has precise measurements in poor environments.

The operating principle of ATOS system is the triangulation. Each three-dimensional measurement points is photographed to a potential triangulation by two different methods. The fringe patterns is projected to the measuring object though measurement probe during measuring, and the cameras on both sides record the pattern. Multiple measurements from different angles at different travel distances can form three dimensional ranges for calculating each three-dimensional points. Then the software automatically converts the respective measurements to a common global coordinate system according to the reference point (circular dot superscript),while measurement data as a point cloud, section or polygon mesh STL (Stereolithography), finally the overall surface is generated. Separate measurements must be repeated when measuring complex, multilateral, porous objects. The volume range of ATOS Compact Scan 2M can be up to 1000×750×750mm.

When a semi-physical model of tower cranes is established, the driver's cab and electric control console are manufactured at 1:1 scale size, but the tower, standard section, slewing table and other metal mechanism manufactured at 1:10 scale, which can fully meet the measurement volume range. A pre-calibrated reference frame or the auxiliary sheet metal parts may be used to measure the comparative small safety devices, and the photogrammetry system TRITOP is applied to record reference mark in advance for very large measurement objects. We also can use using the functions ATOS software to fill the measured digital surface small holes. After measuring multilateral treatment is processed through software to eliminate overlapping triangles, and transform triangle mesh density according to different surface curvature. At last the grid is edited including cross-complementary holes, smooth grid, thinning grid, create a grid bridge, repair mesh, fine mesh and so on. The measurement dissatisfied places such as oil, scratches, etc can be repaired. The borders, corners and other deficiencies can be refined after multilateral process. All users without coordinate measuring technology and experience also can smoothly and quickly set up modeling through the ATOS system.

The foundation, metal structure, anchorage device, the main components, the main safety device of TC5610 tower crane are rapidly modeled and model libraries are built through the ATOS system. Figure 2 is a operator cab model of tower crane.

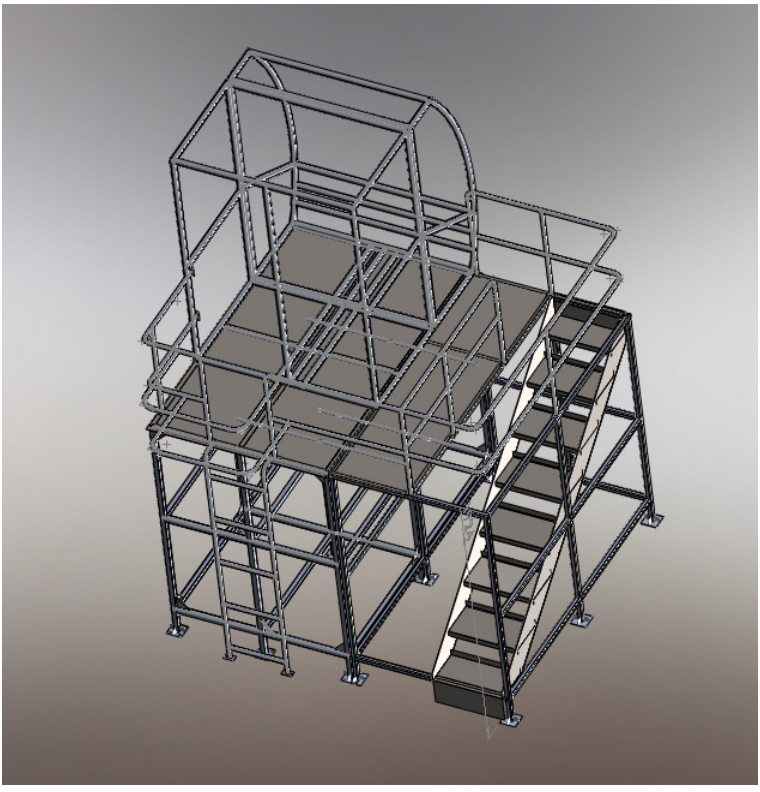

Fig. 2. Operator cab model of tower crane

4 Realization of Tower Crane's Aerial Scene and Multi-channel Projection

VR technology is heavily dependent on the visual and auditory mode. Therefore, a realistic vision system that can change in real time according to operation is necessary to insure effect for the tower crane virtual system. In this paper, a tower crane environment scene is created by image-based panorama generation technology. The outside scene mainly includes work site, unfinished building, component billets and so on. When tower crane works, the outside scene changes in real time according to trajectory of sling load. Different from bridge crane, tower crane work is aerial, the scene in front of tower crane operator is an aerial view. Therefore, when designing the projection system, we should put the horizontal arranged bridge crane system into vertical arranged system. Secondly, the tower crane cab rotates with rotary table, the height of the cab is not change, but the bridge crane cab moves with main girder. So we must set right view point to simulate operator's sight. The out view should change with the view point.

In image modeling and real-time rendering, some pictures of materials or textures are high resolution, so the referenced files are large, system rendering engine needs to process large amounts of texture data, especially for complex polygon rendering terrain. We can slice the map file, and cut three-dimensional models and textures simultaneously and seamlessly, so the system can call them according to the display for efficiency. When displaying geographic model, the system selectively call model slices and texture slices synchronously according to the visibility of individual slices, and then render the scene. This approach enables the system avoiding the entire model and texture processing when rendering geographic models, so that reducing system capacity [3].

Using a large display device can allow many people to observe and interact with a virtual system. Although right now the tower crane virtual system only allows single operation, but for creating basis for simulating multiple tower cranes, multi-channel stereo projection system is necessary. And multi-channel stereo projection system can have larger displaying size, higher resolution, wider visual field, more content and can provide more powerful visual effects and immersive. Along with the rapid development of domestic projection technology, the formerly defects of projection such as high price, lack of brightness, short life of bulb are overcome. Therefore, on account of cost, we can use multi-screen video card and three short focal length projections to compose the three-channel large-screen projection display system.

5 Tower (Wirerope, Sling Load) Multi-load Case Virtual Dynamics Simulation and Motion Trajectory Planning

In order to obtain real training effect, tower crane training and examination system must carry on the simulation experiment and virtual interaction research based on the physical properties, namely, dynamics analysis and statics analysis. Dynamics analysis is to calculate the, trajectories of the tower, the jack arm and the sling load under different load and amplitude conditions which are used for collision detection,

interference test, simulation of failure and accidents, etc.; Statics analysis is to calculate stress distribution and deformation of the tower, the jack arm and the wire rope under different load, different braking time and different running speed, in order to simulate various models of tower crane under the real conditions.

We adopt two particle models for deflection dynamics research of sling load-wire rope-trolley system. We import virtual prototype into ADAMS software, add corresponding constraint, calculate the motions under various working conditions, get the equation of motion and calculates the motion trajectory [7][8]. We do collision detection and interference inspection by simulating collisions between jack arm, sling load and high voltage transmission line, surrounding buildings, adjacent tower crane. students are examed through the action of various kinds of security devices.

The wire rope is a narrow mass object having certain flexibility. In simulation process, in order to reflect the flexibility and the dynamic characteristics of wire rope, we should divide the wire rope into segment, approximating each segment as a rigid ball (points), then connect the adjacent rigid ball (points) by various joints. Through this method and the swing equation iteration, we can simulate motion of the entire wire rope. We research tensile damping coefficient and torsional damping coefficient of node joints, as well as the influence of binding parameters on the simulation. After amounts of physical experiments, we get a good simulation result.

6 Virtual Assembly for Tower Crane Installation, Jack-up, Disassembly

Compared with once installation, repetitive operation for bridge crane, there are frequent installation, disassembly, jack-up operations in the tower crane usage. A lot of tower crane accidents happen in the processes. In this article, with the aid of virtual assembly technology, virtual assembly-disassembly training function module is developed. Combined with big screen, it can be provided for more operators to do virtual disassembly, virtual assembly and virtual maintenance. This multi-person practice can significantly improve the training efficiency. The system simulates the whole assembly process through visual, tactile effect. The system can check the operators' capability such as identification ability for tower cranes structure, components and parts, safety equipment, the ability for evaluating operating time and space, the ability for assess disassembly sequence plan, and so on.

Virtual assembly for tower crane installation, jack-up, disassembly also need motion simulation and trajectory plan, which used in collision detection, interference test so that can simulate the deformation of tower crane structure, simulate the wrong operation. Two kinds of collision detection should be handled: collision detections between the parts, collision detection between interactive tools and parts, in order to determine whether the parts have been checked or loosen, whether the corresponding operation can be performed.

With the help of data glove to manipulate objects in the virtual scene, the participant can move and rotate freely in space, and is not limited to a fixed location, The operation is more flexible, comfortable, optional, and the participant can experience the sense of immediacy. Through the 3d space tracking locator disassembling training, the participant can experience real-time interactive visual simulation [10].

7 Expert System of Examination Simulation and Breakdown Reappearance

The tower crane fault database is designed combined with tower crane norms and standards about design, manufacture, installation, disassembly and inspection. The system can select certain combinations of failures to simulate and examine when training and examining trainees. Visual examination scene can be saved and played back. The key of saving and play scene is data compression.

The system can design and develop operator training question database for the training requirements, to record key operations and play them back in full training and examination processes at the modes with commanders or without commanders, evaluation of training effectiveness is given in accordance with national requirements at last.[11]

8 Conclusion

Many technical problems on virtual reality technology have been solved after years of development, but there are many difficulties to be overcome in realizing a simulation system with fully usability and high Immersion and experience sense, which can be controlled costs and put into application according to engineering practice and application needs at the same time. This paper compares the different points of developing virtual operating simulation systems in between tower crane and bridge (door) crane, the latter has been researched successfully and put into application. The key technologies need to be concerned are analyzed ,which point out the direction for further development and application and plan the interface for further research. Future research will focus on the virtual operating visual reproduction of tower crane based on CCD area array, GIS map reproduction and remote control of group tower crane operation based on the internet, anti-collision detection technology of group tower crane operation, and create a virtual remote monitoring system to realize the remote virtual real-time interaction with tower crane. The virtual reality technology will be better applied in tower crane safety supervision.

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