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Research Article

Study on Virtual Prototype of Two-freedom Mechanism for Potato Harvester Elevator

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Abstract: In order to solve the motion collision of potato harvester elevator, ADAMS and MATLAB are integrated and used to perform their dynamic simulation. Simulation methods for mechanical systems and control systems integration based on ADAMS/MATLAB are applied, the dynamic properties of the entire system is analyzed, as a result, Virtual prototype technology is used to the simulation analysis and the pre-description of the motion collisions of a two-freedom mechanism for potato harvester elevator and the feasible solution for its motion control is set up. Based on the system motion analysis, the elevator positioning control algorithm is proposed and the dynamic properties of the mechanical system and the control system are matched up.

Keywords: Collision protection, dynamic property, position control, potato

INTRODUCTION

The potato harvester equipped with elevator can dig, transfer and collect potatoes at one operation pass during the work that can minimize tuber damage and reduce labor force and also increase production efficiency. Potato-damage rate is one of the critical factors in measuring the quality of potato harvesters and also a key indicator in measuring the technology level of potato harvesters. Currently during harvesting operation, the harvester operator must adjust the elevator's position frequently to keep a proper distance between the end of harvester elevator and potato pile to avoid tuber damage resulted from unreasonable distance between the end of harvester elevator and potato pile. This distance should be kept at a certainty range during the harvesting, because if the distance is too big, a lot of bruised tubers occurs as the tubers fall from the end of harvester elevator into the trailer; in the other way, if the distance is too short, tuber may be damaged by harvester elevator ends and results tuber quality and storage problems. In addition, the danger accident maybe happened if the elevator's position cannot be controlled reasonably and timely, such as the collision between the elevator and the trailer.

4UFD-1400 type potato combine harvester was developed Gansu Agricultural University exhibited better performances and adaptation on the dry land potato harvest, especially for fully-mulching dry land, but its potato damage rate was 4.2% (Wei *et al*., 2013). A certain potato digger in poke finger's wheel was designed, which performed smoothly in digging, lifting and transporting without any block and potatoes were separated effectively from soil, but damage rate was 4.5% (Wu *et al*., 2010, 2011). A disc ce-grate type potato digger was designed, which performed smoothly in digging and transporting, the separation effect was efficient, but damage rate was 4.3% (Shi *et al*., 2012). Moreover, these potato harvesters have not arm equipment and cannot transport the potato to loading trucks. For instance, 4 SW-40 style and 4SW-130-150 style potato harvester designed by Inner Mongolia Agricultural University (Zhao *et al*., 2000; Yan, 2001; Zhao *et al*., 2007; Yang, 2009), CPP-XH-150 potato digger manufactured by Modern Agricultural Equipment Technology Co., Ltd., 4U-1 potato combine harvester and 4UW-120 potato digger designed by Chinese Academy of Agricultural Mechanization Sciences (Zhou, 2004), a new potato combine harvester designed by Gansu Agricultural University (Song and Wang, 2009), 4KU-130/150A elevator chain harvester for tuber crops (Zhou, 2008). There are two ways in avoiding collision: one is to add protective covering, gasbag or infrared distance sensor to real time detect the collision to control the elevator; the other is by using position information of feedback device from the pre-descript information in computer to judge whether collisions will happen (Hajime *et al*., 1999). The potato harvester designed by China Agricultural University can transport potato to truck and the motion collision of potato harvester elevator was researched (Jia *et al*., 2005; Jia, 2006; Liu *et al*., 2009).

In recent years, research on the mechanical damage and mechanics properties of fruits and vegetables has attached great importance (Bentini *et al*., 2006). The application of virtual prototype technology in this study

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is to simulate the machine motion and get the pre-description position data, then according to the algorithm to control the motion of the elevator, to solve the motion collision of potato harvester elevator.

METHODOLOGY

Feature-based parametric modeling of the vibrating screen:

The classification and structure of the vibrating screen parts: New vibrating screen was designed by Inventor on the foundation of the digger vibrating screen design. Main structure is: curving shaft, screen frame, suspended arm, tail screen axes, screen strip and the screen axes bracket. The curving shaft revolves to arouse the screen body to do a to-and-fro swing. Tubers are spread on the transfer belt irregularly.

The parts model establishment and interference test of assembly preparing: Subdivide the vibrating screen into the series characters and save it in the characteristic database. Each character has technique parameters such as size and benchmark etc. Take the screen frame as an example to build up parts model: get a needed character according to the screen frame shape, including stretch and drill, the length of the screen frame is 400 mm, width is 600 mm, the immobility bore diameter of the tail screen axes is 10 mm. Inputting parameters to build up entity model, by which only the parameter value is needed to modify while modifying the model. The geometry restriction relation of size is formed while establishing model, restriction relation and design intent keep constant when modifying model.

The assembly function of software is used to assemble each part. Generally, each part contains 6 freedom degrees; the assembly process is to analyze the function of each part and the freedom degree of 6 directions firstly, then to choose the appropriate assembly method, lastly to fix parts. It carries on the interference test after the assembly body is created, make sure of rationality of accessories design and match.

Parts modification design: An Inventor PROGRAM module is used to realize the modification design of the harvester parts, which is mainly about the definition, inputting and modification of the characteristic parameters. After the entity model is set up, the PROGRAM design list of the Inventor software will list all elements of the model automatically.

Input the parameter that have already defined into "the input part" of parts design list and define the corresponding relations of sizes of each part in "the relation definition part". Meanwhile, the mutual restriction relations definition of different size of the same part is still in "the relation definition part", for example, inside diameter has to be less then outside diameter, the wing spread angle of digging spade must change in a certain scope, each part of the same section needs to be in conjunction with others.

Modifying the characteristic parameter is the premise of carrying on modification design, there are two modification methods. Firstly, choosing the name of each parameter according to hint that is attached, make modification item by item. Secondly, Form all parameters that need to be modified into data document, modification can be one-off by the way of reading in the data document. The first method is comparatively slow, which is used to debug the procedure and input variable; the second method has higher efficiency, which is used in a great deal of design.

The virtual machine model for potato harvester elevator: Virtual machine model is completed by Pro/E which belongs to the software of CAD, shown in Fig. 1. First, the model of potato harvester elevator and trailer is set up, then the Mechanism/Pro program is used to build the file that the ADAMS can read and at last, lead the model to the environment of ADAMS.

The simulation of control function: The way of control arithmetic: establish the relative function according to the position information and data calculated from simulation analysis, then program the injudgement orders, input all the necessary information into DSP to realize the control functions.

Analysis of harvester elevator collision: The main reason that collision happen between harvester elevator and potato pile is as follows: The potato pile in trailer is getting higher and higher as harvester continuous working, in addition, the trailer may move in transverse orientation. But in any case, the range of the movement is finite and when it goes beyond the range, the system will give an alarm signal. Figure 2 shows the simple

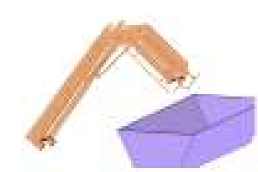

Fig. 1: Boom work in field

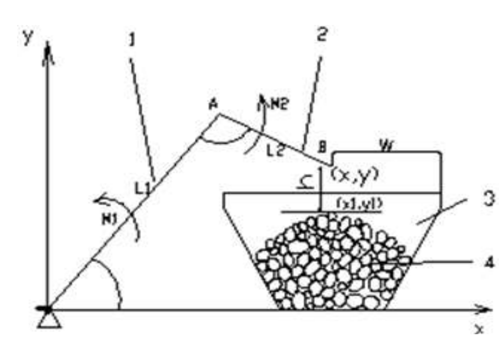

Fig. 2: Simple structure chart

1: Elevator 1; 2: Elevator 2; 3: Truck box; 4: Potato

structure of harvester elevator: the section of long elevator defined as A and that short one defined as B, the joint point of the long elevator to the harvester is defined as the origin of Descartes coordinate, the Z axis parallels the ground and point to the forward direction of the harvester, Y points up and presents the height of the elevator, X axis points to the right side of harvester.

The width of trailer is defined as a, when the machine works, the datum position of the center line of trailer is (2250 mm, 0), the range of position coordinate of trailer permitted to deviate in transverse is from (1850 mm, 0) to (2850 mm, 0) in other words, the two conditions are limited position that is permitted in transverse orientation. It is also assumed that the harvester and trailer work on the relatively smooth ground, which means that the relative position between the bottom of trailer and harvester is unchanged and at the same time the O point and the bottom of trailer are in the same horizontal position.

In vertical direction, the height of trailer is divided into 10 parts, namely 11 interval points defined as m which is the given position of tubers in vertical, the transverse range that tubers be permitted to move is also divided into 10 parts, namely 11 interval points defined as n, then we can get 121 special location calculated from m*n. These special locations are all position coordination as the tuber pile position.

Control method: The principle of control method: by using kinematics simulation, the appreciate position of point B in the 121 conditions can be gotten, namely the corresponding proper angles: θ_1 and θ_2. For the harvester elevator system of two freedoms, the key elements are the rotate angle of long elevator section and short elevator section, expressed as θ_1 and θ_2 respectively. The detailed method is described as following.

Locate the elevator until the point B reaches a suitable position (a right height of the potato pile and the transverse position equals to the center line of the trailer) according to the trailer transverse position and the height of the tuber pile, a position table can be gotten, in which x-axis shows the position of the trailer center and y-axis shows the height of the tuber pile. Every value in the table can be expressed by a pair of data as (θ_1, θ_2). A simulated table created by Adams software shown in Table 1.

Data fit: Because of the elevator structure, the vertical coordinate of point B has the minimum value and the control angle is (45°, 45°), when the tuber pile height is under a certain value, it is unfeasible to adjust the elevator to change the vertical coordinate of point B. In addition, the only possibility for horizontal coordinate of point B to reach the limited data is when the height of potato pile equals to or exceeds a certain data.

When y<800 mm, θ_1 and θ_2 can be read from the table; when 800 mm<y<1600 mm, the value of θ_1 and θ_2 can be calculated from the follow equation:

Table 1: Data of elevator's angle correspond with tuber pile position

	x (mm)					
Z (mm)	1850	1930	…	2250	…	2850
0	69, 53	67, 55	…	58, 61	…	45, 78
160	69, 53	67, 55	…	58, 61	…	45, 78
320	69, 53	67, 55	…	58, 61	…	46, 78
480	69, 53	67, 55	…	58, 60	…	46, 81
640	69, 53	67, 53		58, 63	…	48, 53
……	……	……	…	……	…	……
1440	75, 64	74, 67	…	69, 77	…	58, 98
1600	78, 70	76, 71	…	70, 80	…	59, 102

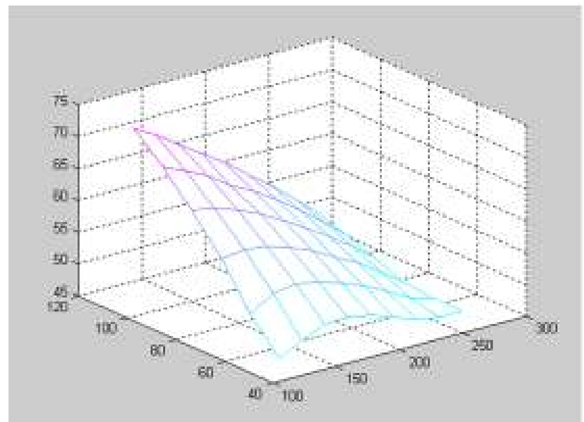

Fig. 3: Fit data of θ_1

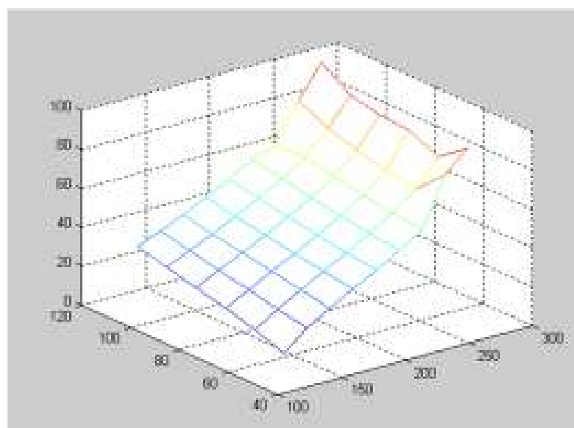

Fig. 4: Fit data of θ_2

$$\theta_1 = 1.3\times10^{-6}x^{-2} - 1.3\times10^{-5}y^2 - 4.4\times10^{-4}xy - 3.2\times10^{-3}x + 2.1\times10^{-3}y + 78.3 \quad (1)$$

$$\theta_2 = 8.4\times10^{-6}x^2 - 4.37\times10^{-6}xy + 8.2\times10^{-6}y^2 + 4.7\times10^{-3}x + 4.9\times10^{-3}y + 53 \quad (2)$$

Figure 3 and 4 shows the fit data of point B corresponding to potato piles.

Control flow chart: Based on the above results, the flow chart of control system is designed as Fig. 5. W shows the distance between the end of elevator and the wall of trailer and h is the distance between the end of

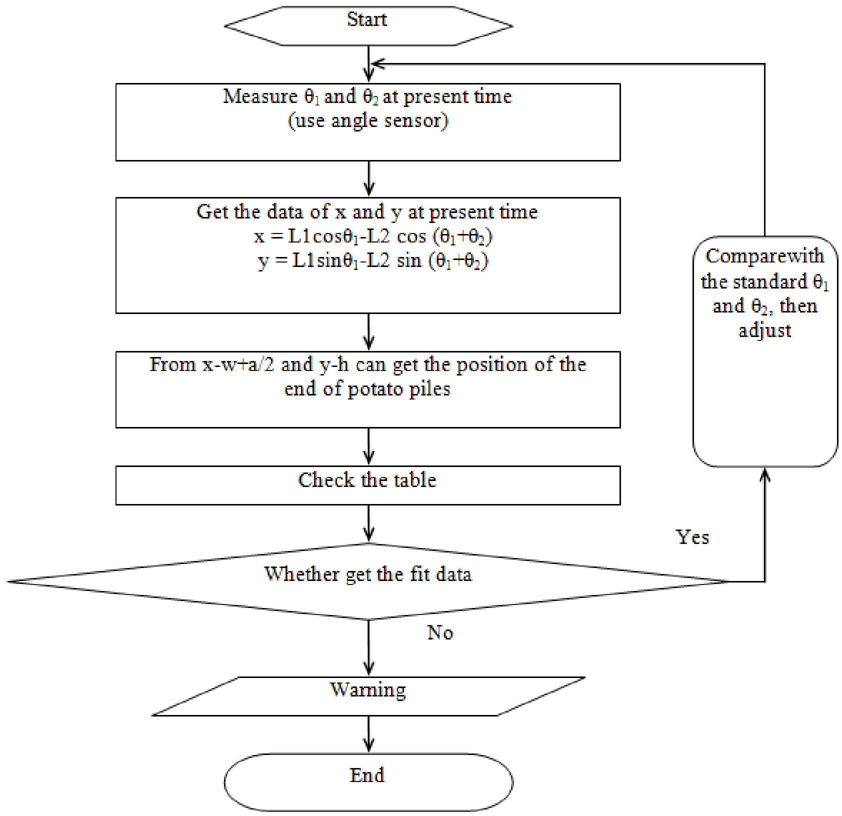

Fig. 5: The flow chart of collision protection

elevator and tuber pile. The data of w and h can be measured by the range sensor.

DYNAMIC CHARACTERISTIC SIMULATION BASED ON THE INTERCOMMUNION PLATFORM OF ADAMS AND MATLAB

In order to analyze the unitary dynamic characteristic when designing system and analyzing collision avoidance simulation, dynamic simulation is needed. For complex module of control system and mechanical system, if use MATLAB separately, calculation of transfer-function of complex mechanical system is needed and if use Adams only, it will be difficult for control system to input information. However, if these two software are cooperated, that is, MATLAB used to the control system part and ADAMS to the mechanical part, a mechanical-electrical integration module could be built in which both software advantages are sufficiently utilized and the advantages of simulation test can be better presented (Wang and Zhang, 2005).

MATLAB represents the of mathematics simulation software and ADAMS is the representative of kinematics of multi-body system simulation software, both have their own characteristics:

- The MATLAB is suitable for the control system modeling, the relation of transfer function is explicit, the blocking of structure make it easy and convenient to modify model and more important is easy to apply control system.
- The Adams model is intuitionistic, the relation of a majority of transfer function conceals in the machine structure inner part, the accuracy of model is high and it is easy to understand the real product when seeing the model in ADAMS.

Mechanical-electrical integration model of harvester elevator is built up based on ADAMS and MATLAB. The mechanism model exported from Pro/e is kinematics of multi-body in ADAMS environment, electronical part is established by SIMULINK of MATLAB.

To integrate the ADAMS and MATLAB, it is necessary to define control relation in logic, the relation between input and output according to each request, explain as follows:

MATLAB session:

- Change MATLAB directories to the one in which the Adams can reside.
- Run the file named "*.m" in MATLAB, create a series of system variables, such as the input variables, output variables and directories etc.
- Create new Adams_sys control block in MATLAB.

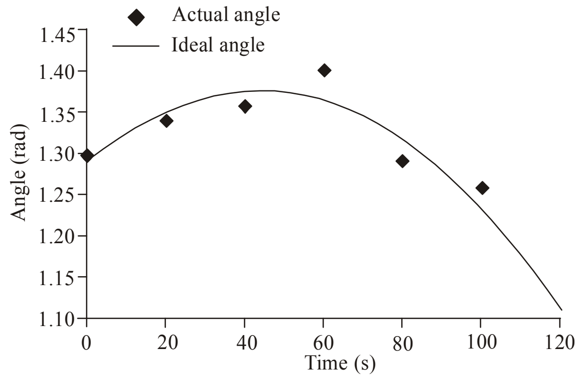

Fig. 6: The track of θ_1

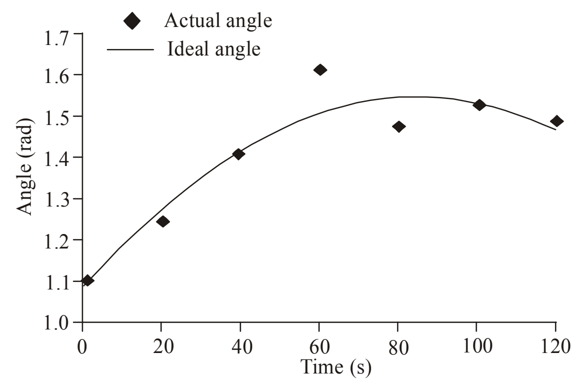

Fig. 7: The track of θ_2

ADAMS session:

- Open the block of control plug-in which belongs to ADAMS/view, so ADAMS can export file.
- Create the variables of plant-input and plant-output as input and output variables of the control block. The plant-input variables need to be accordant with the ADAMS input parameters and the plant-output variables need to be accordant with the ADAMS measure parameters.
- Set the Adams directories as the target directories, name the file, choose the input and output variables, then select the export from the control block, so ADAMS can export and create a series of files, including the file of *.m format that can be run in MATLAB and the files of *.cmd, .adm and *.shl formats, these files include all information of the virtual prototype.

RESULT ANALYSIS

According to the model, the various none-linear factors consist in the system, for example, the change of the center of gravity will cause the change of torque and of working environment etc. All these factors effects on the dynamic characteristic of system should be analyzed. Under the actual working environment, the distance between the elevator end and tuber pile needn't be controlled very strictly, it will meet the requirement of control system as long as the distance is kept in a reasonable scope.

Figure 6 shows that the move track of θ_1 with time in work, the curve represents the ideal value of θ_1 with time changed, "*" means the actual value of θ_1, through calculation, the average value of track error is 0.01 rads, the biggest distance error is 0.02 rads. Figure 7 shows that the move track of θ_2, through calculation, the average value of track error is 0.02 rads, the average error is 0.07 rads.

From above analysis, the error of θ_1 and θ_2 are all in the allowed scope, i.e., the actual move track of elevator is very similar to the ideal track, which proved that it is feasible to apply the pre-description algorithms for potato harvester elevator.

CONCLUSION

The application of computer simulation and virtual prototype technology could efficiently, accurately and visually obtain the information and data needed and avoid a complicated manual calculations and damage tests of physical prototype machine. Manpower and resources can be saved, at the same time provided a credible basis for the control algorithms. Simulation results shown that the control algorithm can not only low the cost, but also can obtain a good result of collision protection.

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REFERENCES

Bentini, M., C. Caprara and R. Martelli, 2006. Harvesting damage to potato tubers by analysis of impacts recorded with an instrumented sphere. Biosyst. Eng., 94(1): 75-85.

Hajime, K., A. Tatsuo, I. Arai-Kenji *et al*., 1999. Real-time obstacle avoidance for robot elevator using collision jacobin. Proceeding of the 1999 IEEE/RSJ International Conference on Intelligent Robots and Systems. Kyongju, Korea, 1999: 617-622.

Jia, J., 2006. Design and experiment study on the critical parts of potato harvester. Ph.D. Thesis, China Agricultural University, Beijing.

Jia, J., D. Zhang and X. Hao and H. Liu, 2005. Parametric modeling and computer simulation of potato harvester parts. Trans. Chinese Soc. Agric. Mach., 36(11): 64-67.

Liu, B., D. Zhang and J. Li, 2009. Design on MZPH 820 single-row potato harvester. Trans. Chinese Soc. Agric. Mach., 40(5): 81-86.

Shi, L., J. Wu and W. Zhao, W. Sun, D. Wang *et al*., 2012. Design and experiment on potato digger of disc ce-grate type. Trans. Chinese Soc. Agric. Eng., 28(24): 15-21.

Song, Y. and F. Wang, 2009. Overall design of a new potato combine harvester. J. Gansu Agric. Univ., 44(1): 151-154.

Wang, T. and H. Zhang, 2005. Co-simulation of control system based on Adams and Matlab. Mech. Eng. Automat., 30(3): 79-81.

Wei, H., D. Wang, W. Lian, S. Shao, X. Yang and X. Huang, 2013. Development of 4UFD-1400 type potato combine harvester. Trans. Chinese Soc. Agric. Eng., 29(1): 11-17.

Wu, J., H. Li, W. Sun, X. Huang and B. Sun, 2010. Design of potato digger in poke finger's wheel type. Trans. Chinese Soc. Agric. Mach., 41(12): 76-79.

Wu, J., H. Li, W. Sun, X. Huang and W. Zhang, 2011. Experiment on poke finger wheel type potato digger. Trans. Chinese Soc. Agric. Eng., 27(7): 173-177.

Yan, J., 2001. Design of 4SW-40 potato digger [J]. Shanxi Farm Mach., 6: 32.

Yang, L., 2009. Simulation and optimization on parameters of separation of potato digger. Ph.D. Thesis, Inner Mongolia Agricultural University, Hohhot.

Zhao, M., S. Zhao and D. She *et al*., 2007. Combined separation type potato digger. J. Agric. Mech. Res., 29(4): 69-72.

Zhao, M.Q., W.G. Dou and S.J. Zhao and W.L. Du, 2000. The development and the exploitation of a new model of potato harvester. J. Inner Mongolia Agric. Univ., 21(2): 91-96.

Zhou, L., 2004. A new style potato combine harvester [J]. Farm Mach., 9: 37.

Zhou, L., 2008. 4KU-130/150A elevator chain harvester for tuber crops [J]. Hebei Agric. Mach., 2: 37.