Study on Behavior Simulation for Picking Manipulator in Virtual Environment Based on Binocular Stereo Vision

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Abstract—**Aiming to uncertain problem in the process of picking manipulator location and behavior decision-making in complex environment, an approach for picking manipulator location and behavior simulation integrating binocular stereo vision together virtual simulation technical was discussed. Firstly, the imaging of picking target and environment were gained by binocular stereo vision, secondly, the result data of picking target and environment after the imaging being handled were mapped into virtual environment, picking manipulator behavior decision-making and motion path planning were implemented by software simulation technical, picking manipulator accurate location was realized in virtual environment. Finally, the simulation motion data in virtual environment were transmitted to control motors at manipulator joint by USB interface, control motors drive manipulator moving automatically to the picking target position. The experimental platform was consisted of CCD stereo vision and simulation software, a location simulation system was developed by VC++ and EON SDK.**

I. Introduction

As to simulate manual picking action to finish fruit picking, a large number of advanced intelligent control technologies need to be used in the intelligent agricultural picking manipulator system. Automatic picking operation is a changeable and complex process. One of key steps is to control manipulator, so that a manipulator moves its terminal performer to approach fruits, and then locates them as well as clamping them. Because some uncertainty problems always exist in environment and picking targets are kinds of biological flexible body which cannot be broken in picking operation, a picking manipulator should give a new position of a variable target each time in picking process and should control the clamping force appropriately so that it cannot damage fruits. Compared to a manipulator used in industrial area, an agricultural picking manipulator is characterized by difficult precision positioning, complex decision-making, and low success rate in picking [1].

Agricultural experts have made a great deal of studies on picking robots. Naoshi Kondo and many other researchers in Japanese Okayama University had developed a tomato picking robot which has 7 movements degree of freedom (DOF). A visual system is composed of color camera and image processing card. It is used to select and identify the mature fruits and implement precise positioning. A cucumber picking robot developed in Japan measures target locations by using binocular stereo vision system, finds fruit stems by using fruit stems detector which is located on a terminal performer, positions a cucumber by using mechanical positioning fingers. Kawollek and many other researchers solved the problem of mechanical target positioning in automatic picking by using three dimensional (3D) modeling technologies [2]. This could help find accurately the positions of certain fruit stems by using optimal visual algorithm. Alessio and many other researchers studied a visual position of orange picking robot, by combining virtual coordinates and 3D simulation [3]. Tiezhong Zhang and his colleagues regarded the position of strawberry center of gravity and picking point as key problems in robot picking operations. They used vision to study and do some correlated experiments [4]. Xinzhong Wang and his research team analyzed error reasons about detecting spatial position of tomato. They revised error employing neural networks [5]. Xingjun Zou and her colleagues studied picking positioning and extraction of behavior knowledge about picking operations in virtual environment (VE). They conducted the picking behavior modeling and simulation using intelligent reasoning technique [6]-[7].

The above analysis shows that researches on agricultural picking robot at home and abroad focused mainly on vision, graphics processing, mechanism, control and other aspects. In the development of picking robot and its key components, they took mainly methods of empirical designs, experiments, and single field simulation, and constructed fewer systems of virtual design and virtual simulation to simulate as well as evaluate whole comprehensive performance about picking robots. This paper explores an approach for positioning and behavior decision-making of picking manipulator from the angle of multi-domain design knowledge fusion. Experiments on model are done by transmitting hardware testing data to simulation environment, fast reconstructing the picking target and its environment in VE, and analyzing simulation behavior of the picking manipulator. By taking the simulation results in VE as the control information of picking manipulator, the optimal decision-making and control of picking manipulator ontology could be realized. The method based on the combining of virtual design and integral simulation can solve

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effectively problems of precise positioning of picking manipulator and complexity of behavior decision, and reduce development costs of picking manipulator and improve development level of design on agricultural picking manipulator.

II. Hardware Experiment Platform

When using the combination methods of hardware and simulation to analyze positioning mechanism of picking manipulator and behavior decision-making, the simulation platform that including hardware should be constructed firstly, then hardware test data about position information of picking target are collected and transmitted into VE, and simulation experiment on model should be done by simulating uncertainty disturbance of picking target in VE. Based on the method of the knowledge representation, extraction, modeling and algorithms about the robot's picking behavior and mechanism, this paper realizes the analysis of picking manipulator behavior, which based on knowledge fusion.

The experimental platform is shown in Figure 1. It consists mainly of cameras, picking manipulator body, and background computer. Two cameras are used as binocular in binocular stereo vision system to acquire target and environmental image. The background compute is used to collect the uptake images by the two cameras, compute 3D coordinates of target in picking coordinates, and construct quickly the picking target and picking scene in VE. Using algorithms of movement modeling, vision and collision, the background computer completes decision-making and route planning of picking manipulator, so that it could give access to precise positioning of picking manipulator in VE. Then the background computer delivers movement data in VE to control motors locating at manipulator ontology by using USB interface, so that they can drive links of manipulator to move and realize automatic positioning to picking target.

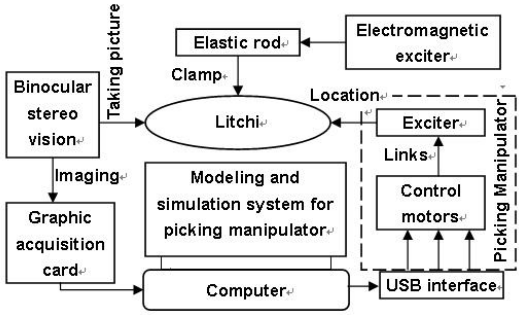

Fig. 1. Hardware experiment platform.

III. Collection of Binocular Stereo Vision Information

Conception of binocular stereo vision refers to using of two fixed CCD cameras of similar performance for acquisition of two images of same scene, and computing 3D information of the scene by acquired two 2D images.

In a process of cameras imaging, a position of target imaging is related to geometric position of corresponding surface point of an object in space. Imaging model can be described as the following functional relationships:

$$\begin{cases} L_{left} = F_{left}(P_{left}) \\ L_{right} = F_{right}(P_{right}) \end{cases}. \quad (1)$$

Where:

P_{Left} and P_{Right} refer to the left and right image coordinates of objectives.

L_{Left} and L_{Right} refer to 3D coordinates of target in the camera coordinates.

F_{Left} and F_{Right} refer to camera imaging model.

Stereo calibration of the binocular stereo vision system refers to getting of relative position of the two cameras, which is described by rotation matrix R and translation matrix T.

$$\begin{bmatrix} L_{right} \\ 1 \end{bmatrix} = \begin{bmatrix} R & T \\ 0^T & 1 \end{bmatrix} \times \begin{bmatrix} L_{left} \\ 1 \end{bmatrix}. \quad (2)$$

By model building of binocular stereo vision system, the relationship between 2D image coordinate and 3D space coordinate is listed as following:

$$\begin{cases} L_{left} = F_{left}(P_{left}) \\ R \times L_{left} + T = F_{right}(P_{right}) \end{cases} \quad (3)$$

If the image coordinates P_{Left} and P_{Right} of an arbitrary space point in the two cameras could be gotten, then 3D coordinates L_{Left} and L_{Right} of the specified point in left and right camera coordinates will be gained by solving the above equations.

IV. Behavior Modeling and Decision-Making

Targets of agricultural picking manipulator's operations are flexible and vulnerable fruits whose size and location are uncertain. Surrounding environment and weather are also always uncertain and bad. Sometimes manipulator operations are obscured for some other things, such as leaves and shadows. Acquired knowledge information is prone to influencing from noise. So behavior and decision-making of agricultural picking manipulator have much more characteristics of complexity and uncertainty.

A. Motion Modeling of Picking Manipulator

The picking manipulator based on this experimental platform has six *DOF*, in which five joints are rotation joints and one joint is translation joint. Coordinate system of Denavit-Hartenberg is used to determine parameters and relations of each link, and space relation of two neighboring links is described by utilizing 4×4 homogeneous transformation matrix, then a motion equation of the picking manipulator could be established. Figure 2 is the link coordinate systems schematic diagram about starting reference location of each joint in picking manipulator.

Picking manipulator motion can be regarded as relative motion of link coordinate $\{T\}$ comparing to link coordinate $\{O\}$.Its starting state and target state should be described firstly. Motion equation of 6 *DOF* picking manipulator is listed as follow:

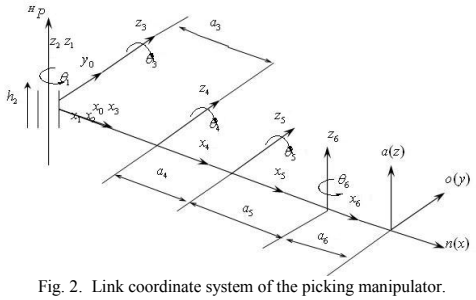

Fig. 2. Link coordinate system of the picking manipulator.

$$ {}^{0}T_{6}={}^{0}T_{1}\cdot{}^{1}T_{2}\cdot{}^{2}T_{3}\cdot{}^{3}T_{4}\cdot{}^{4}T_{5}\cdot{}^{5}T_{6}=\begin{bmatrix} n_x & o_x & a_x & P_x \\ n_y & o_y & a_y & P_y \\ n_z & o_z & a_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4) $$

Here, n_x , n_y , n_z , o_x , o_y , o_z and a_x , a_y , a_z represent sequentially projecting components (Direction Cosine) about x, y, z axes of unit vectors $\vec{n}, \vec{o}, \vec{a}$ onto base coordinate $\{O\}$. P_x , P_y , P_z are coordinate positions of an arbitrary point in a link coordinate.

Motion planning for picking manipulator requires descriptions for each mid-point that emerges in movement process. In another word, picking process should be described. Picking manipulator movement may be represented by nodes sequences of a manipulator end-effectors' position and orientation, while each of such nodes is described by homogeneous transformation from link coordinates to a base coordinate. This correspondent joint variable can be solved from Kinematic reverse solution program. Its inverse transformation matrixes are quoted as follow:

$$ T^{-1}=\begin{bmatrix} n_x & o_x & a_x & \vec{p}\cdot\vec{n} \\ n_y & o_y & a_y & \vec{p}\cdot\vec{o} \\ n_z & o_z & a_z & \vec{p}\cdot\vec{a} \\ 0 & 0 & 0 & 1 \end{bmatrix}. \quad (5) $$

B. Motion Modeling of Picking Manipulator

Only supported by behavior knowledge database, can agricultural picking manipulator make an accurate decision to picking actions in the complex operating environment? According to characteristics of complex picking behavior of such manipulator, knowledge extraction and modeling at different levels could be conduct.

As to related common-sense knowledge about manipulator end-effector's position and orientation, structure, description of environment and picking action, a method combining association rules and object-oriented method is used to construct a common-sense knowledge base. Then decision knowledge based on rules solving and classes matching will be acquired.

A function of association rules is to make clear that how much emergence of some items t_j influence emergences of others in item sets $T\{t_i \mid i=1,2,\cdots,n\}$. Those rules can be cited in an initial action planning of picking manipulator to make the decision-making system possess prior knowledge in order to lead a behavior scheme decision. For example, virtual system firstly conducts an initial action programming, and then it can give suggestion and matching issues on picking, scene, fruit trees and the weather. In order to guarantee correctness of those actions and pluck ripe litchis, the picking behavior depends mainly on reliability degree. When data acquiring from sensors shows that it is light red litchi, the reliability degree is 0.85, thus manipulator plans the picking behavior. The system will automatically search scene target knowledge that matches with reliability degree value in the knowledge base while depending on the reliability degree value we talk above. The common-sense knowledge of litchi picking behavior in the knowledge base can be described as following:

LZ=1 # Litchi tree.
Varietal=2 # `Feizixiao' varieties.
Color=3 # Light red.
Mature=1 # Maturity.
CF=0.95 # Reliability.

Target knowledge, of a specific scene, including a manipulator position is acquired by sensors. This can be described as following:

LZ=1 # Litchi tree.
High-Z=0.1 # Height of target on the axis Z.
…
Action=1 # Take actions.
CF=0.9

The rules listed above can be formalized into two rules for decision-making:

Reasoning formalization for `*Feizixiao*' Litchi picking: *IF* { *LZ*(*i*)=1 and *i Varietal*=2 and *Color*=3 then *Mature*=1}

Behavior decision of manipulator: *IF* {*LZ* (*i*) =1 and *Color*=3 and *Mature*=1 then *Action*=1}

Questions of uncertainty that may appear in the picking behavior can be solved by constructing similar case knowledge base, from which closest behavior knowledge by using a method based on Case-based Reasoning (*CBR*). Then visual knowledge base of 3D model that consists of VR, target model, and manipulator mechanism model can be called directly by the system. By category, complex actions that cannot be described accurately into some simple actions should be transformed in order to reduce the complexity of decision-making and reasoning. Combining of the behavior by utilizing of knowledge fusion technique can make decision-making results closer to objective facts.

C. Behavior Decision Based on Rough Set Theory

Taking behavior problems of virtual manipulators as a kind of design problem and developing design guidelines, behavior design decision by using a method based on rough set and cases could be realized. We knowledge should be classified before actualizing attribute abstraction on knowledge. There are some steps of attribute abstraction from classifications layer by layer. First of all, according to characteristics of manipulator's behavior, a certain type (such as experience, analog, etc.) knowledge could be classified, so different divisions of such knowledge attributive abstraction

could be derived. Then, divisions should be classified to meet specific requirements. Finally, attributive sets being hoped to extract by combining those classified information attribute sets could be acquired.

Behavior decision-making is based on the uncertain and multi-attribute decision knowledge. Importance degree of each characteristic could be known by analyzing classified knowledge, and establish decision table (Including contrast of preferential knowledge), from which key property features will be extracted, and then construct models of knowledge reduction and reasoning that based on rough sets. After getting a reasonable and certain design schedule, those models with similarity matching and cases could be fused. Case retrieval includes expression conversion of uncertain problems, establishment of decision table, analyzing of importance of attribute characteristics, and establishment of index. Finally, from comprehensive evaluation of system similarity model and availability, rational decision-making behavior will be acquired.

V. Simulation Techniques of Picking Manipulator's Behavior

Real-time positioning simulation of manipulator picking process in VE consists mainly of picking targets, surrounding environment, and dynamic as well as static geometry modeling of a manipulator. Picking targets and surrounding environment are constructed by use of EON Studio nodes function, while geometric properties value of those nodes are generated by 3D coordinate information which are acquired by binocular stereo vision. Determined space coordinate of picking targets and obstacles by specific data calibration can provides analyzing data for motion planning. Attribute characteristics of nodes originate from segmentation processing on the images which are acquired by binocular stereo vision, and also from extracting information, such as color, gray and brightness.

Static and dynamic modeling is involved in a picking manipulator. In order to raise the system display speed and

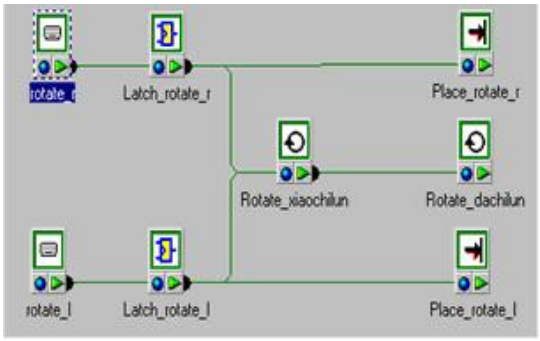

Fig. 3. Routing mechanism.

consider simultaneously that the simulation system is used to verify whether picking manipulator data is fused and whether motion planning and control algorithms are reasonable and correct, static modeling is replaced by simplified geometric model whose geometric dimension and scale are the same as real machines, and dynamic modeling is achieved by refreshing continuously apace coordinate value of static modeling with a group of intermediate data which is analyzed and calculated (by such dynamic modeling) between target location and current location by using inverse kinematics knowledge. Human-computer interaction (HCI) is achieved by using sensors, event-driven and routing (Route) mechanisms in VE, while behavior interaction is achieved by using transmission of information mechanism which is shown in Figure 3.

The behavior simulation system of picking manipulator based on binocular stereo vision takes EON Studio 5.0 as the simulation platform of VE modeling and visualization, and is developed by using VC++ to realize quick reconstruction, manipulator behavior and simulation decision-making of picking targets and their environment which are based on binocular stereo vision. Simulation result is shown in Figure 4.

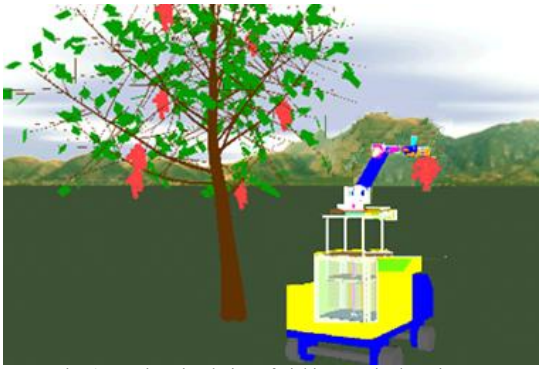

Fig. 4. Motion simulation of picking manipulator in VE.

VI. Conclusion

Aiming at uncertain problem in the process of picking manipulator location and behavior decision-making in complex environment, an approach which integrated binocular stereo vision and virtual simulation technical to acquire picking manipulator location and behavior simulation was discussed. Firstly, the imaging of picking target and environment were gained by binocular stereo vision, secondly, the result data of picking target and environment after the image processing were mapped into VE, while behavior decision-making and motion path planning of picking manipulator were implemented by software simulation technical, thus the precisely locating of picking manipulator was realized in VE. Finally, the simulation motion data in VE were transmitted to control motors at manipulator joint by USB interface, and control motors drove manipulator moving automatically to the picking target position. The experimental platform was consisted of CCD stereo vision and simulation software, and the system of simulation was exploited by VC++ software program and EON SDK.

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