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COMPUTER AIDED DETECTION OF SOLIDS COLLISION IN FMS WITH ROBOT BY CAD SIMULATION

Summary. This paper describes the testing method of solids collision while moving them by an industrial robot (IR) in flexible manufacturing system (FMS). This paper presents the way of modelling 3D space connected with the environment of IR by CAD 3D. The oct-tree method is used to formalize the robot environment description and its computer analysis is presented to detect collisions among the FMS objects and automatically plan of an IR trajectory.

1. Introduction

In the Institute of Machine Technology we have completed the first stage of work on the language for computer off-line programming system for IRb-ASEA industrial robot. The language is called SPMT-R, we have started development a GUI version of the system as well.

The basic objects of FMS (OFMS) are CNC-machines situated in the robot work space. The work space with the OFMS we call the scene (SC).

The GUI of SPMT-R is designed for simulation of IRb robot motion during running of the robot program realized on the first level (**"manipulation level"** [3]) of the off-line robot programming language in SPMT-R [4]. The operator needs the GUI for checking the correctness of the robot program. Recently we have also started the development of SPMT-R on the next level an **"object oriented"** [3] off-line robot programming language. The object oriented version of the system should automaticaly generate the path between the particular positions of the IR trajectory and examine the displacement collisions. On this level of development SPMT-R we would like to obtain the situation in which the robot programmer has to give minimum information about the robot path in SC except the point of end and a pattern of the IR trajectory (e.g. circle, the straight line i.e.).

The first stage of development of the SPMT-R in object oriented level resultated in

elaboration of principles describing:
• scene modelling
• solid relocation modelling
• examining posibility of collisions.
Development of the high level artificial off-line IR programming language link to this level will be the second stage of work with development of SPMT-R

2. Oct-tree modelling theory of the robot scene

2.1 The theory

Because the IR movement take plan in 3D space we employ the oct-tree algorithms [1,2] for solid and solid path modelling and collision analysis. The oct-tree method makes possible creation of simple data structures which describe the 3D world, make it easy for computer to analyse and can be used to represent objects (OFMS and moving objects) in the 3D world. This oct-tree represents a cube which is divided into eight separate cubes named octants. Every one of them has a number called a flag and position in space (the node address) [1,2]. Every octant can be divided (sharing level) to the next octants. If "n" is a current octant sharing level then "n+1" level is called the higher sharing level and "n-1"

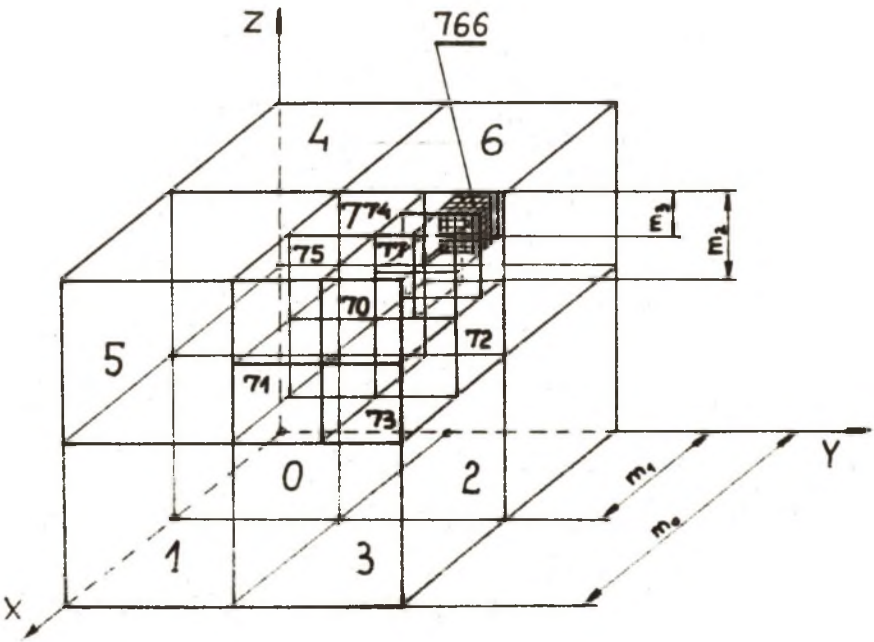

Fig. 1. Sharing of the base octant. The nodes addresses
o - the octants' nodes

level is the lower octant sharing level. Each sharing level in our method we called themodelling level of the SC. The dimensions of each octant are set for every sharing level and are called "octant module" (m_n):

$$m_n = \frac{m_p}{2^n} \tag{1}$$

where: n - number of modelling level,
m_n - module of octant on n - level,
m_p - module of octant on the lowest sharing level (n=0).

Employing the oct-tree algorithms it is fairly easy to describe any octant as a chain of numbers including flags of octants starting from the lowest level (the node address). On each sharing level we have octants numbered (the flag): 0,1,2,3,4,5,6,7 [1,2]. The further numbers of octant on each sharing level give its node address. Octant numbered O_{766} (where 766 is its node address) is the 7th octant on the first sharing level (the lowest level), 6th octant on the 2nd sharing level (in octant O_7) and is 6th octant (O_6) in octant O_{76} on the 3rd sharing level (fig. 1). If X_k, Y_k, Z_k are the coordinates of octant O_k (coordinates of its node, [1,2]) then coordinates of the node of the octant on the lowest sharing level (for n=0):

$$X_O = Y_O = Z_O = 0 \qquad \text{for} \qquad k = 0$$

in the base coordinates system of the SC (k is the node address of octant). Coordinates of nodes of other octants on the n - sharing level are given by the equations [4]: (see fig. 1)

$$X_k = m_p \sum_{j=0}^{n} \frac{i_{x_i}}{2^i}$$

$$Y_k = m_p \sum_{j=0}^{n} \frac{i_{y_i}}{2^i} \qquad \text{and} \qquad i_{0,2,4,6} = 0, \qquad i_{1,2,5,7} = 1 \tag{2}$$

$$Z_k = m_p \sum_{j=0}^{n} \frac{i_{z_i}}{2^i}$$

where: n, m_p, k - like above,
i - the flag of octant on current modelling level.

The octant on the lowest sharing level (n=0) which encloses all scene we named the base octant which module amounts m_p.

2.2 Modelling of the robot scene

For our method of collision analysis we found that all SC we modell by octants. The oct-tree describing SC is created from all octants on successive sharing levels [1,2,4].

Each octant describing the 3D IR work space on each sharing level has characteristic parameter which is called the occupancy coefficient SC by OFMS - w_k.
We define three types of octant occupancy in SC (fig. 2):

- $w_k = 0$ for totally empty octants,
- $w_k > 0$ for totally occupied octants,
- $w_k < 0$ for partly occupied octants.

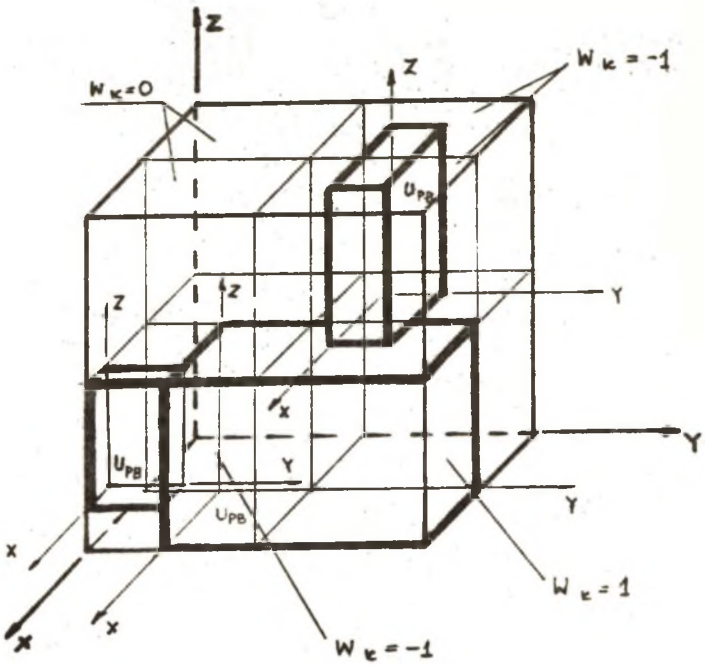

Fig. 2. Examples of octants occupancy
w_k - the occupancy coefficient, U_{PB} - the solid coordinate system
(see chapter 4)

The value of the occupacy coefficient is fixed by comparison coordinates of the octant node (2), its dimension i.e. module (1) with position and dimension of OFMS in the base coordinate system which are describing all SC. The collision of solid carried in SC by IR is checked by analysis of the w_k value parameter on receiving "n" level of SC modelling. For octants with $w_k<0$ - collision is possible and for octants with $w_k>0$ - collision is sure so they are important for checking the collision of a moving solid. Only for octants which $w_k=0$ path IR with solid is sefe. So, checking the parameter w_k for oct-tree which describes the SC it is fairly easy to show the parts of scene where motion of IR can be safe and these where collision between IR and OFMS is possible. For simplification we can eliminate from analysis these octants which have the same types of occupancy: $w_k>0$ (totally occupied) or $w_k = 0$ (totally empty). For further study of occupancy we take into consideration only that octants for which $w_k<0$. The analysis (for next levels) is carried on as long as $w_k=0$ or $w_k>0$. The oct-tree, that we obtain after the analysis includes all octants created during modelling, gives the occupancy matrix of of SC by OFMS which define as [4]:

$$D_{sc} = \left[N^{o}\ of\ \ OFMS\ \ ,\ k\ ,\ w_k \right] \tag{3}$$

where: k - like above,

w_k - occupancy coefficient of octant k.

This matrix enclosed oct-tree modelling SC describing the occupancy of all OFMS in robot working area an l defining occupancy of them.

3. Collision of the moving solid in the SC

The moving solids (MS) in SC are solids displaced by IR (e.g. manipulation objects). For the need of the testing method of collision the moving solids are modelled by oct-tree like the SC (see chapter 2) and we create also the matrix of occupancy of 3D space by the moving solids. For that purpose on each of the solids carried by IR we describe mini octant (MO) which encloses the solid. The occupancy coefficient of octants divided from MO give the matrix of occupancy of 3D space of moving solids D_{MS}.

The collision is possible when the octants occupied by moving solid are occupied by OFMS, too. The collision can be established by comparison of the matrix D_{sc} and occupancy matrix of MO describing the solids (D_{MS}). If octants occupied by OFMS for which

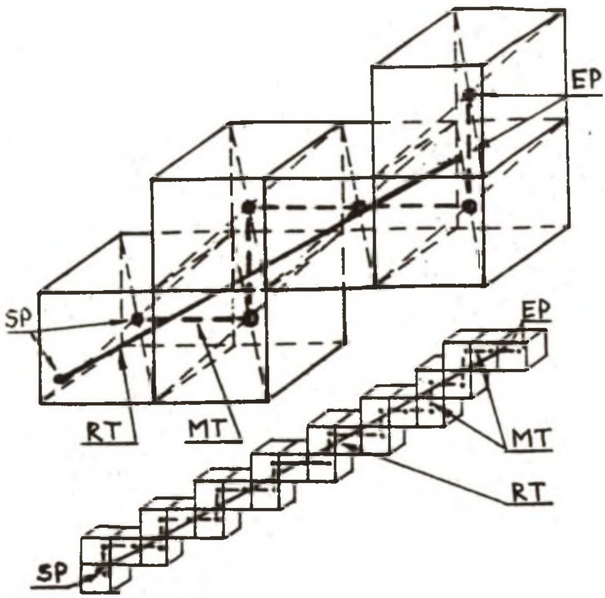

Fig. 3. Description of solid path. The model
MT - the model of IR trajectory, RT - the real IR trajectory, SP - the start point of IR trajectory, EP - the end point of IR trajectory

$w_k(D_{sc})<0$ or $w_k(D_{sc})>0$ do not exist in space of the minimum octant then MS can move unbounded in the space. If modelled MS will move in the SC space, then MS mark real points of robot trajectory in SC. The matrix D_{IR} describing the robot trajectory in space we get by comparison of the w_k of octants describing MS in space ($w_k=1$ in D_{MS}) and octant describing free space for movement ($w_k=0$ in D_{sc}) IR carrying the solid may enter only that place SC for which
$w_k= 0$, that is: $w_k(D_{sc})=0$. In other case collision take place. If coordinates of node of octants and their modules describing SC and MS are known we can define coordinates of the middle of these octants for which:

$$w_k(D_{SC})=0 \qquad \text{and} \qquad w_k(D_{MS})=1$$

for the same place in space can be points of robot trajectory displacing solid in space. That points using by SPMT-R on "object level" make possible to generate the IR trajectory in space between the two predefined points without collision.
During modelling of the motion of the solid the real trajectory is displaced by the model of the trajectory. The model is a polyline running through the centre of modelling MO (fig. 3).

Differences between the real trajectory and modelled trajectory depends on the modelling level. If the modelling level is higher then differences are smaller between the model and real trajectories. If the modelling level of scene and level of moving solid modelling is higher than the level of path modelling then absence of collision in the model is equal to absence of colision in real scene.

4. Transformation of the CAD 3D geometrical data into an octant model

As we have mentioned before for the scene modelling and moving solid modelling in 3D world we need the geometrical parameters of OFMS and MS: location in space, dimesions. As a tool for this description we use:
- special artificial high level programming language of geometrical space,
- CAD 3D system.

In our method we assume that for easier work of programmer of IR description of SC and OFMS will be done in CAD 3D system. Next an input data for octant modelling is the end-file of CAD-3D system (FOC) which includes geometrical information of SC: OFMS, IR and MS.

In our modelling method with CAD [4] the environment of SC can be described only by the basic geometrical solids (prism, cylinder, sphere - fig.4). Application of capabilities of the CAD 3D system makes easy the graphical configuration of SC, the arrangement of OFMS and validity check of creation by graphical display on the PC VDU.
The FOC must be decoded (it is described in suitable format of CAD system: DXF or IGES) and transformed to the form which is needed for octant modelling method.
Every OFMS must be described by thase basic solids and information about thouse solids include:
- definition of the solid coordinate system U_{PB} in the base scene coordinate system,
- geometrical parameters describing the biggest of solid (on fig. 4 parameters: a,b,c,l,r).

After determination the U_{PB} coordinates of and the module of the octant in which solids are included (the minimum octant) we prepare new information set which includes the parameters of octant. This data will be the base for transformation the geometrical data into octants.
All transformation of FOC to suitable form by oct-tree modelling method is realised by

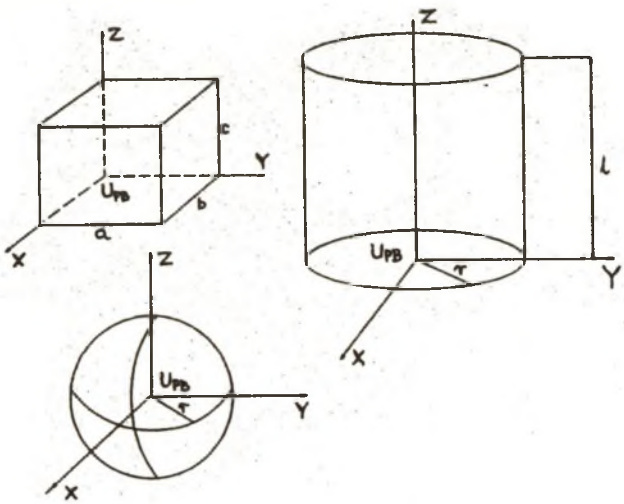

Fig. 4. Parameters of solids describing SC

special module of SPMT-R system on "object level". The result of the oct-tree CAD modelling is checked by GUI. The GUI makes possible:

- **checking of correctness and completness of scene description,**
- **checking of completness of SC octant modelling by drawing D_{SC}, D_{MS} octants matrices on the screen,**
- **checking of the IR trajectory form by graphical representation of D_{IR} matrix.**

5. Conclusion

Method of modelling of SC by octants for collision checking of displaced solids let us find, that:

- CAD system makes the job of IR programmer and job of designer of FMS. easier,
- octant modelling method enables easy data processing and data storing,
- transformation of data from CAD 3D for input data for modelling is very complicated, and needs a special SPMT-R program module,
- the method enables the automatic creation the IR trajectory and planing of the trajectory (e.g. avoiding of obstacles).

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DIE UNTERSUCHUNGSMETHODE DER KÖRPERKOLLISIONIERUNG IN DER ROBOTIESIERTER FLEXIBLEN FERTIGUNGSSYSTEMEN MIT AUSNUTZUNG DER MODELLIERUNG IN CAD

Zusammenfassung

In dem Artikel wird die Untersuchungsmethode der Kollisionierung von Körpern beschrieben, die von einem Industrieroboter (IR) in den Flexiblen Fertigungssystemen (FFS) verschoben sind. In dieser Arbeit wurde das Modellierungsverfahren von Arbeitsmileus IR mittels des CAD 3D Systems vorgestellt. Es wurde für die Formallisierung der Milieusbeschreibung IR und ihrer Computeranalyse die Methode der Oktalbäume ausgenutzt. Das Ziel dieser Methode ist die Entdeckung der Kollision zwischen dem FFS Elementen für die automatische Planung der Robotertrajektorie.

METODA BADANIA KOLIZYJNOŚCI BRYŁ W ZROBOTYZOWANYCH ELASTYCZNYCH SYSTEMACH PRODUKCYJNYCH Z WYKORZYSTANIEM MODELOWANIA W CAD

Streszczenie

Artykuł opisuje metodę badania kolizyjności brył przemieszczanych przez robot przemysłowy (IR) w elastycznych systemach wytwarzania (ESW). W pracy przedstawiono sposób modelowania środowiska roboczego IR za pomocą systemu CAD 3D. Wykorzystano metodę drzew oktalnych do formalizacji opisu środowiska IR i jego komputerowej analizy, której celem jest wykrycie kolizji między elementami FMS dla potrzeb automatycznego planowania trajektorii IR.

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