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Tensor Decomposition of KUKA Industrial Robot (KR16-2) in Rotational System

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Abstract-This paper refers to study of industrial robot (KUKA KR16-2), in which we have considered the matrix decomposition and tensor decomposition model in rotational motion. We have considered robotic matrix & Tensor and defined a modal product between robot rotation matrix and a tensor Further we have proposed the third order tensor for the motion of Industrial robot and tried to find out the useful result. At last we have shown that the tensor model is providing alternate way to find the solution.

I. INTRODUCTION

A robot is a component of an Advance Industrial Manipulator with the help of integration of advance motion system and Critical Function Transformation in motion control. Other components of this system i.e. machine tools, control devices, different auxiliary elements, and transport machines. The KUKA robotic arms are heavy and it is powerful machines capable of inflicting serious harm by crushing or laceration. The machines each weight around 250kg and draw a peak power of around 10 kilo-Watts. The robotic cell is gauzed for protection and safety depending upon safety standards employed by various organizations. The gauzing also serves to trigger an emergency stop if anyone enters into the cell. In literature review, the Artificial Intelligence based robotic motion path implementation by advance integration software like RTOS VxWorks v8.2.2. [6][7]. We are trying to attempt a less complex, easy to implement and both critical solution for KUKA Industrial Robot

II. INDUSTRIAL ROBOT & TENSOR

A tensor is a multidimensional array, in which the order of tensor denotes the dimension of the array. As an example, a scalar is just associate order-0 tensor, a vector order-1, a matrix order-2, and any tensor with order-3 or larger is delineated as a better order tensor. For this paper we'll be specialize in the only higher-order tensor for industrial robot, the order-3 tensor, which might be envisioned as a form of Rubik's cube according to robotic manipulator KUKA KR16-2.[1],[2], [3]. An1 x n2 x n3 third order tensor for KUKA Industrial Robot is a n3 array of n1 x n2 matrices. This third order tensor will be denoted by upper case script letters (A, B, C, ……) . Aijk refers to the number in row i and column j of matrix k of A as per Robotic motion structure. The set of 3rd-order tensors for industrial robot with real number entries is denoted Rn1 x n2 x n3

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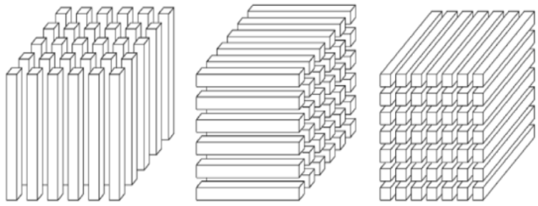
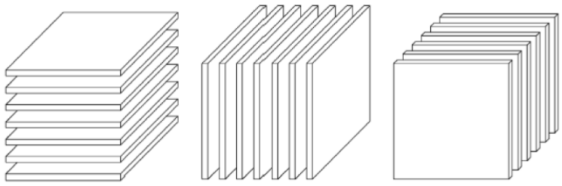
According to Industrial Robot KUKA KR16-2, rotation motion is governed by higher order tensors. Analogous to rows or columns of a matrix, 3rd-order tensors have robot implementation route. Robot route is implemented by 3^{rd} order tensor. These robotics route areas are units which are equal to vector parts of matrix. There are rows, columns, and robot routes, the area units visualized in Figure 1. Under Robotic motion a 3^{rd}-order tensor is sliced in three dimensions having horizontal, lateral, and frontal robotic slices. For industrial robot the area units are visualized in Figure 2.[3],[5],[7],[8]



Robot Column Robot Row Robot route
Figure 1



Horizontal slices Lateral slices Frontal slices
Figure 2

III. ROBOTIC MATRIX & TENSOR

Consider A is a 3^{rd}-order tensor and $A \in R^{n1 \times n2 \times n3}$. Then the modal unfolding $A_{(k)}$ is the matrix $A_{(k)} \in R^{nk \times N}$ where N is the product of the two dimensions unequal to n_k.[2] [6], [8]
For a 3^{rd}-order tensor, $A \in R^{n1 \times n2 \times n3}$, there are 3 modal un folding and in general a 3^{rd} order tensor has 3^{rd} modal unfolding. As a simple example the modal unfolding for $A \in R^{3 \times 4 \times 2}$ are shown below, where A_1 and A_2 are the frontal slices of A.

$$A_1 = \begin{bmatrix} X_1 & Y_1 & Z_1 & P_1 \\ X_2 & Y_2 & Z_2 & P_2 \\ X_3 & Z_3 & Z_3 & P_3 \end{bmatrix} \qquad A_2 = \begin{bmatrix} R_1 & S_1 & T_1 & U_1 \\ R_2 & S_2 & T_2 & U_2 \\ R_3 & S_3 & T_3 & U_3 \end{bmatrix}$$

$$A_{(1)} = \begin{bmatrix} X_1 & Y_1 & Z_1 & P_1 & R_1 & S_1 & T_1 & U_1 \\ X_2 & Y_2 & Z_2 & P_2 & R_2 & S_2 & T_2 & U_2 \\ X_3 & Y_3 & Z_3 & P_3 & R_3 & S_3 & T_3 & U_3 \end{bmatrix}$$

$$A_{(2)} = \begin{bmatrix} X_1 & X_2 & X_3 & R_1 & R_2 & R_3 \\ Y_1 & Y_2 & Y_3 & S_1 & S_2 & S_3 \\ Z_1 & Z_2 & Z_3 & T_1 & T_2 & T_3 \\ P_1 & P_2 & P_3 & U_1 & U_2 & U_3 \end{bmatrix}$$

$$A_{(3)} = \begin{bmatrix} X_1 & Y_1 & Z_1 & P_1 & X_2 & Y_2 & Z_2 & P_2 & X_3 & Y_3 & Z_3 & P_3 \\ R_1 & S_1 & T_1 & U_1 & R_2 & S_2 & T_2 & U_2 & R_3 & S_3 & T_3 & U_3 \end{bmatrix}$$

Using the definition of modal unfolding we can now define a modal product between a Robot Rotation matrix and a tensor.

The Modal product, denoted A_K, of a 3rd –order tensor $A \in R^{n1xn2xn3}$ and a matrix $U \in R^{Jxnk}$, where J is any integer, is the product of modal unfolding $A_{(K)}$ with U,

Such that

$B=UA_{(k)} = A_k U$------------------- (1)

These two operations will be used to generalize the standard singular value decomposition for rotation of robot.

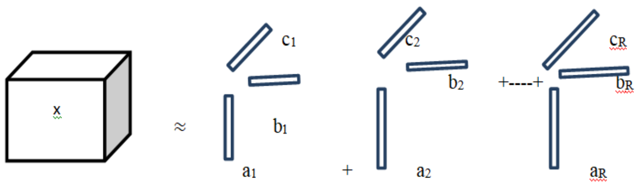
A 3rd – order Tensor, A_{ijk}, is defined as a sum of vector outer product, denoted o, that equal or approximately equal A,

For R=rank (A)

$A=\sum_{r=1}^{R} a_r \odot b_r \odot c_r$-------------------- (2)

And for R<rank (A)

$A\approx \sum_{r=1}^{R} a_r \odot b_r \odot c_r$------------------ (3)



The vectors of composition ar, br,and cr for 1<r ≤R1, are often compiled into the columns of the matrices A,B and C respectively;

$A=[\![A,B,C]\!]$-------------- (4)

This type of matrix multiplication is often denoted by the ⨀symbol.L

For instance,

A⨀B=[a1|a2|a3|……………….|an]

⨀[b1|b2|b3|…………an°bn=[a1ob1|a2ob2|a3ob3|…………|an o bn] ------------------------(5)

The Rotation of Industrial Robot (KUKA KR 16)

A robotic matrix M, we would like to approximate it as well as possible with another robotic matrix. M of a lower rank robotic matrix, minimizing the norm of the difference between the two robotics matrices;

Min $\|M-\widehat{M}\|$ with $\widehat{M}= AB^T$

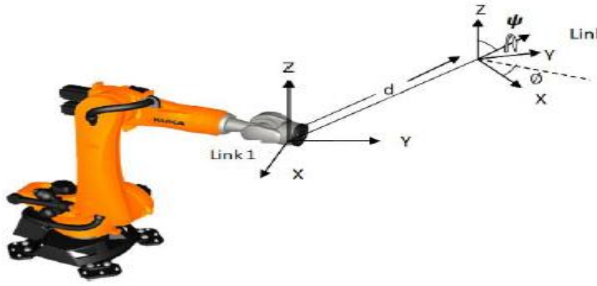
Interesting an invertible robotic rotation R together with its inverse R^{-1} between robotic function A and robotic function B^T and absorbing robotic R on the left with A and R^{-1} on the right with robotic function B^T we can again construct two matrix $\tilde{A}$ and $\tilde{B}^T$

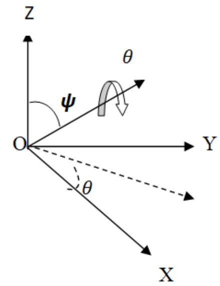
$\widehat{M}= AB^T= ARR^{-1}B^T= (AR)(R^{-1}B^T)$

$= (AR)(BR^{-T})^T=\tilde{A}\,\tilde{B}^T$______________(6)

It means that the rank decomposition of a robotic matrix is generally highly non-unique.

A rotation matrix for robot is used to rotate a robotic motion properties this rotation matrix represented by a 3rd order tensor of KUKA Robot, about an axis or axes. This process is done to orientation ally average robotic motion over axes that are known to allow robotic free rotation. The robotic rotation matrix commonly used to do this is below for KUKA Robot and the corresponding axes of robotic rotation of KR16-2.[3] [4] [6] [8]





It is immediately evident that the robotic rotation matrix gets complex quickly when robotic rotation an object in 3 dimensions around 3 rotational axes for KUKA Robot.[3][5][7]

If final matrix of Robotic Rotation Function (RRF) in Rotation in three dimensions is given by,

[R= [R_1⨀R_2⨀R_3]]--------------(7)

Cos $(\emptyset)$ $(\psi) - cos\,(\theta)\sin(\emptyset)\sin(\psi)$ - cos $(\theta)\cos(\psi)\sin(\emptyset) - \cos(\emptyset)\sin(\psi)\sin(\theta)\sin(\emptyset)$

R = Cos $(\psi)\sin(\emptyset) + \cos(\theta)\cos(\emptyset)\sin(\psi)$ cos $(\theta)\cos(\emptyset)\cos(\psi) - \cos(\emptyset)\sin(\theta)$

Sin $(\theta)\ sin(\psi)$ cos (ψ)sin (θ) cos (θ)

$C\emptyset c\psi - C\theta S\emptyset S\boldsymbol{\psi}$ -$C\theta C\varphi S\emptyset - C\emptyset s\psi$ $S\theta\ S\emptyset$

R = $C\psi s\emptyset + C\theta C\emptyset S\boldsymbol{\psi}$ -$C\theta c\emptyset c\psi - S\emptyset S\boldsymbol{\psi}$ -$C\emptyset S\emptyset$

$S\theta S\boldsymbol{\psi}$ $C\psi S\theta$ $C\theta$

As per above mentioned content, we refer to robotic rotating a 3rd order tensor,

$$A_{ijk}= A^{qrs} R_{qi} R_{rj} R_{sk} \text{------------(8)}$$

IV. CONCLUSION

On the basis of definition of modal matrix and tensor, we have defined a modal product between a robot rotation matrix and a tensor and found the rank of decomposition of robotic matrix is generally highly non unique. Further on account of investigations of industrial robot and tensors, it has been obtained that the route of industrial robot is implemented by third order tensor. Hence we are in position to conclude that the tensor model of industrial robot provides the alternate way to find out the solution in comparison to other existing robotic path implementations.

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