тирования позволит сделать проектирование более эффективным, повысить качество управления процессом коллективного проектирования, а также сократить сроки разработки.

Библиографические ссылки

1. *Афанасьев А. Н.*, *Хородов В. С.* Распределенное проектирование структурно-функциональных моделей, представленных на языке VHDL // Вестник Ульяновского гос. тех. ун-та. – 2014. – № 2(66). – С. 41–45.

2. *Афанасьев А. Н.*, *Игонин А. Г.* Применение нейросемантического подхода для анализа и синтеза функциональных моделей в системах проектирования // Вестник ИжГТУ. – 2007. – № 1. – С. 66–69.

3. *Green R.* Облачные технологии в САПР // CAD/CAM/CAE Observer. – 2010. – № 6(58).

4. Нечеткие методы согласованного управления в многоагентных системах / Н. Ю. Мутовкина, В. Н. Кузнецов, А. Ю. Клюшин, Б. В. Палюх // Вестник ТГТУ. – 2013. – Т. 19. – № 4.

5. *Афанасьев А. Н.* Методология графоаналитического подхода к анализу и контролю потоков работ в автоматизированном проектировании сложных компьютеризованных систем // Вестник Ульяновского гос. тех. ун-та. – 2011. – № 3(55). – С. 48–52.

6. *Скотт Чейт.* Преобразование Web-приложения в мультитенантное решение SaaS [Электронный ресурс]. – URL: www.ibm.com/developerworks/ : ресурс IBM для разработчиков и ИТ-специалистов. URL: http://www.ibm.com/developerworks/ru/library/cl-multitenantsaas/ (дата обращения: 13.06.2014).

7. *Хородов В. С.*, *Игонин А. Г.* Технологии распределенного проектирования. // Вестник Ульяновского гос. тех. ун-та. – 2014. – № 1. – С. 55–59.

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Technologies for Distributed Design of VHDL-objects

The paper proposes the multi-agent distributed design system for structural and functional models presented in the language VHDL. Roles of agents are described. The implementation structure of the system is developed based on SaaS and CORBA technologies.

Keywords: design, distributed systems, multi-agent system, SaaS, CORBA technologies.

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EXPLOITING TWO AMBIDEXTROUS ROBOTIC ARMS FOR ACHIEVING COOPERATIVE TASKS

This paper is about designing two ambidextrous robotic arms to achieve tasks cooperatively. The design is concerned with offering a flexible and humanlike dual arm behavior to be used as a true production partner with humans in different industrial and medical applications. After introducing the kinematics of this design, a new switched two functionality controller will be used to guide the actuators with an efficient method for planning the movement. Also a new and efficient algorithm of collision avoidance will be used. Experiments and results are given using the task of the Russian Matryoshka doll assembling and disassembling, which can be generalized to do any other sophisticated tasks.

Keywords: multi-agent systems, delicate control, robotic manipulators, inverse kinematics, collision avoidance.

Of course two arms are better than one, because one arm can’t clap alone. So there is always a need for robot arms which achieve tasks cooperatively. Ambidexterity is the state of being equally adept in the use of both right and left appendages, such as the hands. It is one of the most famous varieties of cross-dominance. People that are born *ambidextrous* are extremely rare. In tennis Maria Sharapova is a perfect example of a player who is ambidextrous [1]. MacDonald Dettwiler designed and manufactured the two armed robot Dextre as a part of the international space station to replace some activities which required spacewalks; it was launched in 2008 on mission STS-123. Automakers use dual-arm robots to shorten the cycle time of treating components surfaces. A 7-axis robotic arm allows multiple positions and orientations same as a 6-axis articulated arm but instead of having just one configuration per pose it has 50 % more dexterity and offers many configurations, like a human arm. Motoman for example introduced three dual-arm model series starting from 2004: DA, DIA, and SDA series, which were used for assembling automotive parts, electric motors, and appliances. ABB started in 2009 developing Frida, a dual-arm robot equipped with vision cameras, which can cooperate with workers safely and intuitively, to use it in consumer electronics industry production scenarios. Barrett Technology Inc. in 2010 joined the DARPA autonomous robotic manipulation program, which hopes to develop a dual-arm robot by 2014 that lets a robot autonomously manipulate, grasp and perform complicated tasks after receiving high-level direction. Intel Personal Robotics Lab unveiled HERB also in 2010, a robot that features dual WAM arms, which can pick up various small items, offer them to people and place them in a different area while avoiding obstacles. Apart from these dual-arm robots, the single WAM arm has been used in manufacturing, surgical, space, and research applications. The arm is highly responsive to contacts all across its link surfaces, not just at the tip end. Rather than relying on active force or torque sensors, it precisely controls motor current. In the future, dual-arm robots will become true partners to humans in various jobs, using the same tools, such as industrial and medical assistance tools and devices [2]. ISO 10218 standards for industrial robot safety, believed to help promote human-robot assembly line collaboration [3]. Christian Smith et al. investigated all the dual arm technologies and methods up to the year 2012 and showed that they were mostly using bimanual operation of two manipulators, which were separately handled and their control is based on visual servoing. In this paper the dual arm robot is handled as one entity. Visual servoing is believed not necessary for systematic tasks, that don't require visual perception, and are handled using tactile perception only. The aim is to design a flexible and humanlike ambidextrous dual-arm behavior in order to achieve cooperative tasks to use it as a real partner with humans in different applications (medical, industrial, and military), by exploring new artificial intelligence and dynamic programming algorithms. Design a new and efficient method and algorithm for planning the movement and balancing the mechanism called Ellipse Normal Inclination. Design a new and efficient method and algorithm for collision avoidance called Ellipsoid Intersection Location. Design a new switched dual-functionality controller for every joint to guide the robot's actuators to enable shifting between two movement regimes, one in the reachable workspace, and the other in the ambidextrous workspace.

Inverse Kinematic analysis

Arm and hand postures are independent of each other, so it is possible to find the forearm and upper arm posture to match the wrist position and determine its joint angles to match the hand orientation; those angles are used later in trajectory planning. Each arm can be modeled as a 7-DOF mechanism as shown in figure 2, and the transformation matrix for its base where $\theta_x = \theta_z = \theta_y = 0°$ is:

$$T_{base} = \mathrm{Rot}_x(\theta_x)\ \mathrm{Rot}_y(\theta_y)\ \mathrm{Rot}_z(\theta_z).$$

Denavit-Hartenberg parameters are:

For left arm

i	α*i* – 1	*ai* – 1	*di*	θ*i*
1	π/2	0	0	θ1 + π
2	π/2	0	0	θ2 + π/2
3	π/2	0	0	θ3 + π
4	π/2	0	*L*1	θ4
5	–π/2	0	0	θ5 – π/2
6	–π/2	0	*L*2	θ6 + π/2
7	π/2	0	0	θ7 + π

For right arm

i	α*i* – 1	*ai* – 1	*di*	θ*i*
1	π/2	0	0	θ1
2	π/2	0	0	θ2 – π/2
3	–π/2	0	0	θ3 – π
4	–π/2	0	–*L*1	θ4
5	π/2	0	0	θ5 – π/2
6	–π/2	0	–*L*2	θ6 + π/2
7	π/2	0	0	θ7 + π

L_1 and L_2 are the length of the upper and lower arm parts. The DOFs at the wrist are not considered, so there are 3 DOFs at the shoulder and one DOF at the elbow:

Redundancy can be constrained by specifying the elbow position. θ_4 can be derived based on shoulder position Ps, elbow position Pe, and wrist position Pw, as:

$$W = \| P_w - P_s \|,\quad c_4 = \frac{L_1^2 + L_2^2 - W^2}{2L_1L_2},$$

$$s_4 = \sqrt{1 - c_4^2},\quad \theta_4 = \pi - A\tan 2(s_4, c_4).$$

Then θ_4 is used to derive ${}_4^3T$:

$${}_7^0T = T_0^{-1}.{}_7^{base}T = \begin{bmatrix} r_{11} & r_{12} & r_{13} & {}_7^0p_{wx} \\ r_{21} & r_{22} & r_{23} & {}_7^0p_{wy} \\ r_{11} & r_{11} & r_{11} & {}_7^0p_{wz} \\ 0 & 0 & 0 & 1 \end{bmatrix},$$

$${}_7^0P_w = \left[{}_7^0P_{wx}, {}_7^0P_{wy}, {}_7^0P_{wz} \right]^T,$$

$${}_7^0P_e = \left[{}_7^0P_{ex}, {}_7^0P_{ey}, {}_7^0P_{ez} \right]^T =$$

$$= \begin{bmatrix} {}_7^0P_{ex} \\ {}_7^0P_{ey} \\ {}_7^0P_{ez} \\ 1 \end{bmatrix} = T_0^{-1}.\begin{bmatrix} {}_7^{base}P_{ex} \\ {}_7^{base}P_{ey} \\ {}_7^{base}P_{ez} \\ 1 \end{bmatrix} = {}_4^0P_e,$$

$${}_4^0T = {}_1^0T.{}_2^1T.{}_3^2T.{}_4^3T =$$

$$= \begin{bmatrix} & & & {}_4^0P_{ex} \\ & {}_4^0R & & {}_4^0P_{ey} \\ & & & {}_4^0P_{ez} \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} & & & L_1c_1s_2 \\ & {}_4^0R & & L_1c_2 \\ & & & L_1s_1s_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

$c_2 = \dfrac{{}_4^0P_{ey}}{L_1}$ (for both arms), $s_2 = \sqrt{1 - c_2^2}$ (for left arm), $s_2 = -\sqrt{1 - c_2^2}$ (for right arm), so: $\theta_2 = A\tan 2(s_2, c_2) - \dfrac{\pi}{2}$.

$c_1 = \dfrac{{}_4^0P_{ex}}{L_1s_2}$, $s_1 = \dfrac{{}_4^0P_{ez}}{L_1s_2}$, so: $\theta_1 = A\tan 2(s_1, c_1) - \pi$ (for left arm), $\theta_1 = A\tan 2(s_1, c_1)$ (for right arm).

Then ${}^0_1T$ and ${}^1_2T$ can be derived. The wrist position with respect to frame2:

$$ {}^2_7T = {}^1_2T^{-1}\cdot{}^0_1T^{-1}\cdot{}^0_7T = \begin{bmatrix} & & & {}^2_7P_{ex} \\ & {}^2_7R & & {}^2_7P_{ey} \\ & & & {}^2_7P_{ez} \\ 0 & 0 & 0 & 1 \end{bmatrix}, $$

$$ {}^2_7P_w = \begin{bmatrix} -L_2c_3s_4 \\ -L_1 - L_2c_4 \\ -L_2s_3s_4 \end{bmatrix} \text{ (for left arm),} $$

$$ {}^2_7P_w = \begin{bmatrix} -L_2c_3s_4 \\ -L_1 - L_2c_4 \\ L_2s_3s_4 \end{bmatrix} \text{ (for right arm),} $$

$$ c_3 = \frac{{}^2_7P_{wx}}{-L_2s_4} \text{ (for both arms),} $$

$$ s_3 = \frac{{}^2_7P_{wz}}{L_2s_4},\ \theta_3 = A\tan 2(s_3, c_3) - \pi \text{ (for left arm),} $$

$$ s_3 = \frac{{}^2_7P_{wz}}{-L_2s_4},\ \theta_3 = A\tan 2(s_3, c_3) + \pi \text{ (for right arm)} $$

Then ${}^2_3T$ can be derived. θ_5, θ_6 and θ_7 can be derived from frame 4 to frame 7 transformation matrices [4, 5]:

$$ {}^4_7T = {}^3_4T^{-1}\cdot{}^2_3T^{-1}\cdot{}^1_2T^{-1}\cdot{}^0_1T^{-1}\cdot{}^0_7T = \begin{bmatrix} & & & {}^4_7P_{wx} \\ & {}^4_7R & & {}^4_7P_{wy} \\ & & & {}^4_7P_{wz} \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^4_7T = \begin{bmatrix} c_5c_6c_7 - s_5s_7 & -c_7s_5 - c_5c_6s_7 & c_5s_6 & 0 \\ -c_7s_6 & s_6s_7 & c_6 & L_2 \\ -c_5s_7 - c_6c_7s_5 & c_5c_7 - c_6s_5s_7 & -s_5s_6 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

(for left arm)

$$ {}^4_7T = \begin{bmatrix} c_5c_6c_7 - s_5s_7 & -c_7s_5 - c_5c_6s_7 & c_5s_6 & 0 \\ c_7s_6 & -s_6s_7 & -c_6 & L_2 \\ c_5s_7 + c_6c_7s_5 & c_5c_7 - c_6s_5s_7 & s_5s_6 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

(for right arm)

So: $c_6 = {}^4_7r_{23}$, $s_6 = \sqrt{1-c_6^2}$, $c_5 = \frac{{}^4_7r_{13}}{s_6}$, $s_5 = -\frac{{}^4_7r_{33}}{s_6}$,

$$ c_7 = -\frac{{}^4_7r_{21}}{s_6},\ s_7 = \frac{{}^4_7r_{22}}{s_6} \text{ (for left arm),} $$

$$ c_6 = -{}^4_7r_{23},\ s_6 = \sqrt{1-c_6^2},\ c_5 = -\frac{{}^4_7r_{13}}{s_6},\ s_5 = -\frac{{}^4_7r_{33}}{s_6}, $$

$$ c_7 = -\frac{{}^4_7r_{21}}{s_6},\ s_7 = -\frac{{}^4_7r_{22}}{s_6} \text{ (for right arm),} $$

$\theta5 = \mathrm{Atan2}(s5, c5) + \pi/2$, $\theta6 = \mathrm{Atan2}(s6, c6) - \pi/2$, $\theta7 = \mathrm{Atan2}(s7, c7) + \pi$ (for left arm),

$\theta5 = \mathrm{Atan2}(s5, c5) - \pi/2$, $\theta6 = \mathrm{Atan2}(s6, c6) - \pi/2$, $\theta7 = \mathrm{Atan2}(s7, c7) + \pi$ (for right arm),

$$ {}^2_5P_w = \begin{bmatrix} -L_2c_3s_4 \\ -L_1 - L_2c_4 \\ -L_2s_3s_4 \end{bmatrix} \text{ (for left arm),} $$

$$ {}^2_5P_w = \begin{bmatrix} -L_2c_3s_4 \\ -L_1 - L_2c_4 \\ L_2s_3s_4 \end{bmatrix} \text{ (for right arm),} $$

Collision Avoidance algorithm

The collision of the two manipulators occurs inside the common work area of their workspace, so if one is in the common work area, the other should absolutely be prohibited to move or pass into this area; however they are allowed to move freely inside their own external work area. Each manipulator as a 3D object will be approximated as an ellipsoid as shown in figure 1.

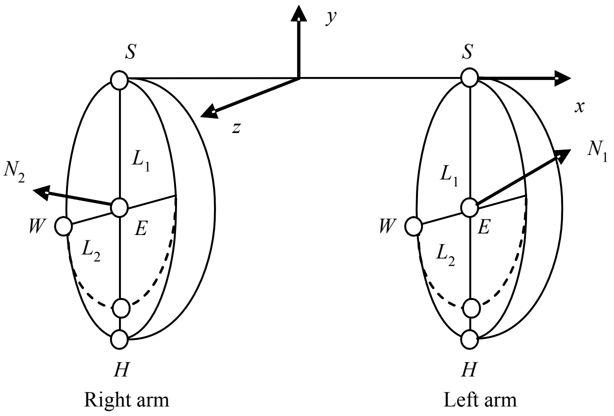

Figure 1. Ellipsoid representation of two arms and principal ellipses in reference to a common coordination system

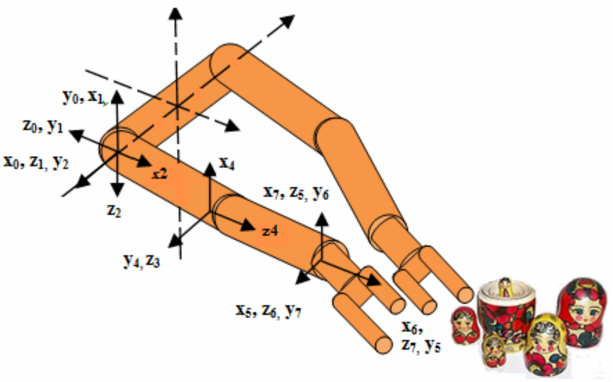

Figure 2. Mantling and dismantling the Matryoshka

Collision avoidance will be based on collision detection by partitioning a window in time into a number of static snapshots, and perform intersection detection on each of these. The number of snapshots depend on the objects size and proximity and the manipulators speed; the outermost doll diameter chosen is D = 8 cm. Arm movement can be divided into coarse, related to the arm upper and lower parts, to which collision is mostly related, and fine one related to hand and fingers. The most critical expected collision is the collision of the arm lower part. Inspired by the human arm it's found that the *Arm Ratio = lower part*$_{avg}$ */ upper part*$_{avg}$ = 28.20/36.46 = = 0.77 ≈ 3/4 to be used in designing the robot arm. The distance between two shoulders is 42.54 cm, i. e. between the bases of the two robot arms where *Base Ratio* = = *upper arm/distance between the two bases* ≈ 6/7. If we take the line of symmetry, there is collision if an arm point *e* on both arms has $(x_{er}, y_{er}, z_{er}) = (x_{el}, y_{el}, z_{el})$. Both the upper arm vector *Pe* and lower part vector *Pw* form a plane which is the principal ellipse in the ellipsoid, where z_3 the axis of the elbow movement is perpendicular on this plane, so it is its normal *N*: $N = Pe \times Pw$. So if we define the angles of inclination θ_{el} and θ_{er} between each of the normal vectors N_1 and N_2, and the reference coordinate system, we can define the posture of the arms to prevent collision and use them for trajectory planning. This technique called Ellipse Normal Inclination reduces the need of using the joints angles to one angle, the normal inclination angle $\theta_e = [\theta_x, \theta_y, \theta_z]$, and speeds up the calculations, and is used for balancing the mechanism. Referring to the ellipses in figure 1 we can define the orientation of both arms to each other in reference to a common coordination system,, using the following equations where *S*, *W*, and *H* are the position vectors of the shoulder, wrist, and hand end-point respectively:

$Sx = c$ (for left hand), $Sx = -c$ (for right hand), $Hx = 0$, $Sy = 0$, $Hy = -2a$, $Sz = Hz = 0$, $Wx = 0$, $Wy = -a$, $Wz = b$

$$\begin{bmatrix} S_x^r \\ S_y^r \\ S_z^r \end{bmatrix} = R(\theta_x)R(\theta_y)R(\theta_z)\begin{bmatrix} \pm c \\ 0 \\ 0 \end{bmatrix},$$

$$\begin{bmatrix} W_x^r \\ W_y^r \\ W_z^r \end{bmatrix} = R(\theta_x)R(\theta_y)R(\theta_z)\begin{bmatrix} 0 \\ -a \\ b \end{bmatrix},$$

$$\begin{bmatrix} H_x^r \\ H_y^r \\ H_z^r \end{bmatrix} = R(\theta_x)R(\theta_y)R(\theta_z)\begin{bmatrix} 0 \\ -2a \\ 0 \end{bmatrix}$$

The rotational speed $\dot{\theta}_e = f\left(\frac{1}{D}, \frac{1}{d}\right)$, where *D* is the object's diameter and *d* is the distance between the manipulator and the object.

Ellipsoid Intersection Location Algorithm:

$$E_i(x,y,z) = (a_{00}^{(i)}x^2 + 2a_{01}^{(i)}xy + a_{11}^{(i)}y^2 + b_0^{(i)}x + b_1^{(i)}y + c^{(i)}) + (2a_{02}^{(i)}x + 2a_{12}^{(i)}y + b_2^{(i)})z + (a_{22}^{(i)})z^2$$

are the two ellipsoid equations, where $i = \{0, 1\}$, and $E_i(x) < 0$ defines their inside and $E_i(x) > 0$ defines their outside. Start at a point x_0 where $E_0(x_0) = 0$, if $E_1(x_0) = 0$, then intersection point is found. If $E_1(x_0) < 0$, then x_0 is inside the other ellipsoid. The path on the 1st ellipsoid with largest increase in E_1 locally is: $\frac{dx}{dt} = \nabla E_1 - \frac{\nabla E_1 . \nabla E_0}{|\nabla E_0|^2}\nabla E_0$.

When $E_1(x_0) > 0$, the tangent direction must be reversed so that Q_1 is decreased as rapidly as possible to 0, in this case: $\frac{dx}{dt} = -\nabla E_1 + \frac{\nabla E_1 . \nabla E_0}{|\nabla E_0|^2}\nabla E_0$.

The differential equation right-hand side reduces to the zero-vector, and its length is used as a termination criterion. A tangent vector for the curve is perpendicular to both ∇E_0 and ∇E_0. The system of equations to solve is: $\frac{dx}{dt} = \nabla E_0 \times \nabla E_1$.

Ellipsoids equations can be rewritten as

$$(x - c_i)^T m_i (x - c_i) = 1,$$

where m_i is positive definite, c_i is the ellipsoid center, $c_0 + t\,V$ is a separating axis where *V* is a unit length vector. The projection of E_0 onto the axis is $I_0(V) = [-r_0, r_0]$: $r_0 = \sqrt{V^T m_0^{-1} V}$.

The projection of E_1 onto the axis is

$$I_1(V) = [V.\Delta - r_1, V.\Delta + r_1]: \Delta = C_1 - C_2,\ r_1 = \sqrt{V^T m_1^{-1} V}.$$

Select an initial *V*. If the ellipsoids intersection $f(V) = I_0(V) \cap I_1(V) = 0$, then they are separated. If $f(V) \neq 0$, then the given axis does not separate the ellipsoids. When the intervals overlap, then $f(V) = [f_0, f_1]$: $f_0 = \max\{V.\Delta - r_1, -r_0\}$ and $f_1 = \min\{V.\Delta + r_1, r_0\}$.

If $f_1 - f_0 > 0$ they overlap, else if $f_0 = f_1$ then there is a single point of intersection, else if $f_1 < f_0$ and $h(V) < 0$ then they are disjoint. So the task is to search the space of unit length vectors, starting at initial *V*, to determine if there is such a vector that makes $h < 0$, and it is enough to determine if $h = 0$ and the graph of *h* has a transverse crossing at that location.

Experiments and results

Usually tasks are divided into *continuous tasks* and *discrete tasks*, continuous tasks usually use *gross motor* skills and discrete tasks use *finer motor* skills. Gross motor skills perform tasks like walking, balancing, crawling. Fine motor skills perform tasks that are precise in nature. Fine motor skills are the coordination of small movements which occur e.g., in the fingers, usually in coordination with the eyes (e.g., working with knitting needles).

Coordination between eye perception and hand action is made by determining the fixed transformation between the gripper coordinate system and the camera taking in consideration the workspace estimate as shown in figure 3, with the following joint angles constraints $-135° < \theta_l < 45°$, $-135° < \theta_2 < 100°$, $0° < \theta_3 < 145°$, $45° < \theta_4 < 180°$. State estimation and feedback control of the hands are necessary to complete the task.

The positions of both obstacles and target are fixed where the doll will be located at $P_m = [0\ 42\ -42]$, and the arms start with an uncertain estimate of these positions with $\dot{\theta}_e \approx 360$ °/s, and $\ddot{\theta}_e \approx 3600$ °/s^2. If an object (hand, obstacle or target) is close to the focus point, the noise perturbing the observation of the object's position will be reduced as a Gaussian function of distance from this point, generating better position estimation, and offering more accurate feedback control of the hands. As observation noise is state-dependent and not Gaussian, a nonlinear filter is required. Due to the obstacles, the cost is not quadratic and dynamic programming algorithm is used [6]. The optimal solution is a feedback policy for controlling the positions of both hands and eye with gradually reducing the focusing spot. Dual-arm robots with humanlike flexibility shown in figure 2 have been our priority, and the experiment used in [4] was mantling and dismantling of the Russian dolls or Matryoshkas which denote a recognizable relationship of similar objects within each other using the algorithm shown in figure 3; this appears in the design of many natural and man-made objects, and can be applied in different industrial and medical applications [2, 7]. For task coordination switching control is used, which means there is one and only one controller active at any given time [8]. The coordinator chooses between the two controllers by consulting a lookup table. Each of these controllers has its own control law and is assigned to the appropriate task. A connected computer calculates the necessary parameters off-line, defines the tasks and sends the necessary information to the lookup table, where using one angle θ_e reduces the calculation to 25 % of the time needed, as shown in figure 4, when the position of the left hand wrist moves from its rest position to point (20, 14, –36) as an example. The precision is measured by the maximum error in the values of the joints angels, and in case of using the ellipse normal inclination method: $e_{\max} = \eta e_N = \dfrac{\eta e_{Pw}}{L_1 + L_2} = \dfrac{28 \cdot 0.0001}{0.4 + 0.3} = 0.004$ rad.

Where η is the gear ration and e_{Pw} is the measured error of the wrist location, L_1 and L_2 are the length of the upper and lower arm respectively. Which is 17.5 % less than the error measured in the other know methods which is about 0.0047 rad.

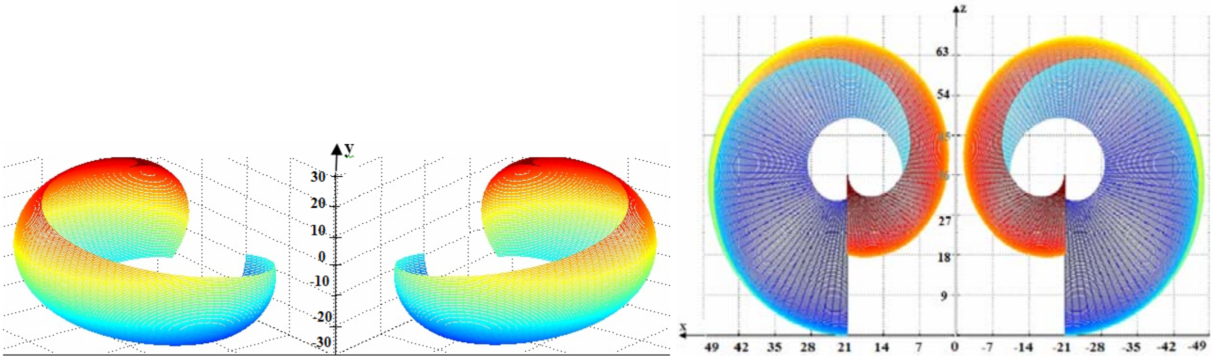

Figure 3. Ambidextrous dual-arm robot workspace

```
dismantle_doll();
Begin
    left_arm_goto_doll_lower_part (position);
    grasp_doll_lower_part();
    right_arm_goto_doll_upper_part (position);
    grasp_doll_upper_part(); lift_doll_upper_part();
    put_doll_upper_part_aside(position);
end;
Number_of_dolls:=enter_nmber_of_dolls();
for doll_number=1 to number_of_dolls then
    Begin
        doll:=doll[doll_number];
        dismantle_doll();
        doll:=doll[doll_number+1];
        right_arm_goto_doll(position); lift_doll ();
        put_doll(position);
    end;
```

Figure 3. The algorithm of dismantling the Matryoshka (to be reversed for mantling)

Angle	Calculation time (sec)
θ_1	0.0151
θ_2	0.0017
θ_3	0.0019
θ_4	0.0024
Total time	0.0211
θe	0.0053

Figure 4. Arm joint angles and θ*e* calculation time

Main program creates two concurrent processes each executes the corresponding controller task (delicate or robust) [8], where within each of the controllers, tasks are served using the priority scheduling algorithm for real time applications. In the task code *controller()* is a function which chooses the appropriate controller and deliver it a task through a two dimension array *task* which has two fields a pointer to the current controller and a vector of the corresponding tasks.

The concurrent controller processes have a mutual exclusion strategy. The dynamic model is computed as a function of the desired path only, so when the desired path is known in advance, values could be computed off-line in the supervisory unit before motion begins. At run time, the pre-computed torque histories would then be read out of memory. The dual-arm payload is 20 kilograms. If mantled on a vehicle it can be used for disarming minefields in military applications. It fits into spaces ergonomically designed for human professionals, and can be easily interchanged with a human co-worker when required.

Conclusion

The dual-arm robot intended to be used in any application where labor involves a specific series of tasks, for handicapped people artificial limbs, and as a partner to: fire fighters for rescuing, workers for manufacturing, doctors for surgery, and as a research platform. Having a solution where several manipulators are involved requires coordination between them. To prevent collision with each other and the surrounding objects, Ellipsoid Intersection Location algorithm was used. Our experiments showed that coordinating between the two arms based on the Ellipse Normal Inclination method offers a more generic, speedy, and precise solution for a wide range of robotic applications. Hands control and balancing the mechanism will be handled in future papers. This paper explores the human behavior and intelligence for solving problems and handling sophisticated tasks to reach algorithms which are used by the human brain for control and making decisions, and to mathematically model definite problems and simulate the required algorithms for solving those tasks. The results showed 25 % speed increase and 17.5 % accuracy increase than other known methods in achieving a complex task which can be generalized to be used in a lot of applications which requires precision and working in real time.

References

1. *Al Akkad M. A.* Robotics as an Efficient Tool in Education // Proceedings of 4th International Conference. – ISTU, 2010.

2. *Ibrahim I. N.*, *Al Akkad M. A.* Inverse Kinematics Solution Improvement Using a Neural Fuzzy Logic Model // ISTU Vestnik. – 2014.

3. *Pires N.* Industrial Robots Programming: Building Applications for the Factories of the Future. – Springer, 2007.

4. *Hamdan B.*, *Kawatli A.* Exploiting two ambidextrous Robotic arms for achieving cooperative tasks : dissertation / supervisor: M. A. Al Akkad. – Computer Engineering and Automation Dept., FMEE, Damascus University, 2010.

5. *Craig J.* Introduction to Robotics Mechanics and Control. – 3rd edition. – Prentice Hall, 2005.

6. *LaValle S.* Planning Algorithms. – Cambridge University Press, 2006.

7. *Skaif T.*, *Al Akkad M. A.* Designing an ad hoc protocol for multi-agent systems : Master thesis / supervisor: M. A. Al Akkad. – Computer Engineering and Automation Dept., FMEE, Damascus University, 2011.

8. *Al Akkad M. A.* Delicate Control versus Robust Control. // ISTU Vestnik, 2013.

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Эксплуатация конечностей двурукого амбидекстрального робота для решения задач, требующих совместной кооперации

В статье рассматриваются аспекты проектирования двух амбидекстральных роботизированных манипуляторов для решения задач, требующих совместной кооперации. Цель проектирования – создание схожего с человеческим амбидекстрального поведения гибких конечностей робота, который может стать настоящим партнером человека для выполнения различных видов работ в области медицины и промышленности. Представлено описание кинематики конструкции, предложена новая переключающаяся система двойного назначения для управления манипуляторами, а также эффективный метод планирования движения. Использован новый эффективный алгоритм предотвращения столкновений. Представлены результаты эксперимента для задачи сборки и разборки матрешки, в дальнейшем реализация может быть перенесена на другие сложные приложения.

Ключевые слова: многоагентные системы, точное управления, манипуляторы, обратная кинематика, предотвращение столкновений.

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КОНЦЕПЦИЯ БЕРЕЖЛИВОГО ПРОИЗВОДСТВА – ОСОБЫЙ «ГЕНЕТИЧЕСКИЙ КОД»

Рассматриваются вопросы организации производства на основе принципов концепции бережливого производства корпорации Toyota. Приведены основные понятия, определения и шаги организации бережливого производства. Рассмотрены ключевые проблемы сложности внедрения концепции на российских предприятиях и возможности их преодоления.

Ключевые слова: концепция бережливого производства, поток создания ценности, потери производства, принцип «вытягивания», повышение эффективности, муда.

В настоящее время бережливое производство является одной из самых востребованных тем в среде российского производственного менеджмента. В связи с этим представляется целесообразным рассмотреть основные понятия данной концепции для достижения ясности в понимании предмета обсуждения.