Content and structure of knowledge base used for virtual control of android arm motion in specified environment

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Abstract. The paper presents the configuration of knowledge base necessary for intelligent control of android arm mechanism motion with different positions of certain forbidden regions taken into account. The present structure of the knowledge base characterizes the past experience of arm motion synthesis in the vector of velocities with due regard for the known obstacles. This structure also specifies its intrinsic properties. Knowledge base generation is based on the study of the arm mechanism instantaneous states implementations. Computational experiments connected with the virtual control of android arm motion with known forbidden regions using the developed knowledge base are introduced. Using the developed knowledge base to control virtually the arm motion reduces the time of test assignments calculation. The results of the research can be used in developing control systems of autonomous android robots in the known in advance environment.

1. Introduction
Building algorithms for the control process of autonomous android robot operating in a planned environment requires a number of factors to be considered. The given control algorithm is implemented as a set of rules and a relevant logic decision mechanism. Also within the assigned time intervals throughout the control process proper estimation of certain parameters should occur. These parameters define the conditions that the specified algorithm should understand. Typically, the algorithm of android control faces unplanned events and unknown situations, and it is desirable that it behaves intelligently in these situations. The behaviour of an autonomous android robot can be improved if the control system takes into account and uses the knowledge base or the past experience of motion synthesis with due account for positions of the known in advance forbidden regions.

2. Problem statement
Let us consider the development technique and the structure of the past experience knowledge base used for the virtual modelling of robot motions in the vector of velocities. Let us remark here that the virtual control of the motion allows the arm mechanism capability to be evaluated before implementing motions in drives with the prescribed position of forbidden regions and the start and end points of the synthesized motion path of the output link centre (OL) [3-7]. The knowledge base of the past experience is the parameter part arranged in arrays defining intrinsic properties of an android arm mechanism as well as properties with due account for the position of the known forbidden regions. These arrays can be calculated in advance to determine the past experience related to the motion synthesis in the vector of velocities. The motion synthesis can be studied in advance at distinct points of the configuration space (defining the service angle along the whole set of possible values of generalized coordinates by instantaneous states implementation [8, 9]). The motion synthesis along the
specified paths of OL (of the arm) in the working envelop with consideration for object obstacles position leading to deadlocks can also be studied [10].

The most frequent movement task for an android is putting on a working object or taking it off the tool rack. Therefore, let us examine the structure of the knowledge base in virtual control of the android arm motion in this example. Suppose we need to model the motion of the arm mechanism to transfer the manipulation object from the point $A^S$ (the start point of the synthesized path) to the point $A^E$ (the end point) considering the location of tool racks $P_1$ and $P_2$ (figure 1).

![Figure 1](image.png)

**Figure 1.** Start and end position of the manipulation object being mounted on the tool racks by android

The position of the points $A^S$ and $A^E$ in figure 1 is assigned by their projections $A^S_1$, $A^S_2$, $A^E_1$ and $A^E_2$. In this figure subscript one or two respectively means that the points belong to the horizontal plane of projection (or the top view) or the frontal plane of projection (or the front view). The general view and the kinematic diagram of an android robot arm mechanism are represented in the paper [8]. Here, it is necessary to clarify whether the arm can reach the target point of the synthesized path using virtual modelling or not. In figure 1 the system of coordinates $O_1x_1y_1z_1$ is connected with the body of the android, the parameters $x_T$, $y_T$ and $z_T$ defining the origin position of this system relative to the inertial coordinate system $O_0x_0y_0z_0$. The parameter $x_t$ determines the minimal assigned safe distance from the android body to the tool racks. The position of the reference point $B^{c2}$ of the bottom tool rack is defined by the coordinates $x_{B}$, $y_{B}$ and $z_{B}$. The virtual modelling problem is solved using the knowledge base of the past experience.

3. **Theoretical basis**

At the first stage of solving the motion problem related to the transfer of the manipulation object from the point $A^S$ to the point $A^{P1}$, and then to the points $A^{P2}$ and $A^E$, it is necessary to evaluate the working envelope with proper account of the location of tool racks. The point $O'$ is considered to be fixed. The
construction of the working envelope with regard to the location of tool racks is studied in paper [11].
The parameters that define the working envelope projections with proper allowance made for the position of tool racks in this paper can be used by one of the component parts of the knowledge base about the past experience.

Let us agree to use the first component of the knowledge base to calculate the optimal rest position (configuration) of the android arm relative to the manipulation object (with the account of the start point $A^H$ of the OL path). The optimal position in motion synthesis in the vector of velocities characterized by the parameters $x_i, y_i$ (figure 1) and generalized coordinates $q_i$ specifies the position of the android arm and body relative to the point $A^S$ at which the solid angle $U_i$ obtained by the instantaneous states implementation takes the maximum value [8]. The specified position of the android robot is calculated for each certain plane of level $\Delta_i$, assigned with a definite step of the coordinate $z_{\Delta i}, z_{\Delta 2}$ and so on (figure 1), the curve of the function being plotted for this coordinate:

$$U_i = f(x_i, y_i).$$  \hspace{1cm} (1)

Let us consider the procedure to determine the graph of the function (1) for the plane $\Delta_1$. To determine the graph of the function (1) and array of configurations where the OL centre coincides with some points $A^S$ of the plane $\Delta_i$, specified with a certain grid space, the starting point $A^{S \Delta 1}$ being prescribed. The parameters $x_S$ and $y_S$ determine the rest position of the start point $A^{S \Delta 1} \in \Delta_1$ by the paths of the OL in the system $O^xS^yS^z$, with the centre of the OL moving in the plane $\Delta_1$ (symbol $\in$ defines that the point belongs to the geometric object $\Delta_i$). Figure 1 does not show the position of the point $A^{S \Delta 1}$. This position coincides with one of the rectangle vertices of the plane $\Delta_1$, its sides being determined by the parameters $\Delta x_5$ and $\Delta y_5$. The set of point positions $A^S \in \Delta_1$, constructed within the specified interval $\Delta x_S$ and $\Delta y_S$ (figure 1) on the plane $\Delta_1$, is obtained by the arm motion synthesis with the range of motion minimization criterion [2, 10]. The specified grid step for definition of points $A^S$ is determined by the modulus of the vector of linear velocity for the OL centre motion in the plane $\Delta_1$. The initial agreed value of the vector $q_{\Delta i}(q_1, ..., q_5)$ corresponding to the OL centre position at the point $A^{S \Delta 1}$ provides the maximum angle $U_i$ value. This value is derived from the analysis of a number of arm configurations that provide the assigned values of parameters $z_{\Delta i}$ and $x_i$. The maximum angle $U_i$ value configuration, obtained by the instantaneous states implementation, is determined from the set of specified configurations [8]. The components of the vector $q_{\Delta i}$ or the values of generalized coordinates $q_1, ..., q_5$ specify the initial configuration relative to the position of the OL centre at the point $A^{S \Delta 1}$. The values of the vector $q_{\Delta i}$ and the values $x_S$ and $y_S$ are read after the motion synthesis for each point $A^S$ of the plane $\Delta_i$. The solid angle $U_i$ obtained by the instantaneous states implementation for the distinct points $A^S$ and values of the vector $q_{\Delta i}$ is approximately determined from the formula:

$$U_s = \left(U_{s, \text{hor}} + U_{s, \text{fr}} + U_{s, \text{prof}}\right) \frac{1}{3},$$  \hspace{1cm} (2)

where angles $U_{s, \text{hor}}, U_{s, \text{fr}}$ and $U_{s, \text{prof}}$ specify angle projections $U_i$ on the horizontal, front and profile planes of projection respectively [8]. The first component of the knowledge base assigned by the array $\Psi_1$ specifies the compliance of the values $z_{\Delta i}$ and parameters $x_i, y_i$ and $q_{\Delta i}$, the angle value $U_i$ being the maximum. This knowledge base is used to ensure the optimal rest position of the arm relative to the start point of the transfer path for the manipulation object. This component of the knowledge base characterizes the intrinsic properties of the android arm mechanism.

Data on the start and end positions of points specifying the synthesized path of the OL motion and the forbidden region positions (of the tool racks $P_1$ and $P_2$) arise as the second component of the knowledge base $\Psi_2$, this knowledge base being the cause of deadlocks [10]. The example of the forbidden regions position $P_1, P_2$ and the path of the android robot arm motion, being the cause of the deadlock, is shown in figure 2a. The motion synthesis along the path $A^{S}A^{P_1}A^{P_2}$ with the point-to-point accuracy being $\delta < 10$ mm is presented in figure 2a. In that case there is a deadlock. Figure 2b shows the motion synthesis along the same path with $\delta < 60$ mm.
Figure 2. Motion synthesis along the path prescribed by the segments $A^sA^p_1$ and $A^p_1A^p_2$: a — with the deadlock occurrence at $\delta < 10$ mm, b — motion synthesis at $\delta < 60$ mm

Figure 2b shows that in the second case a significant deviation from the path occurs. Generally this can lead to the collision of the manipulation object and tool racks. In this case under the prescribed type of configuration, the motion synthesis in the vector of velocities for $\delta < 60$ mm at the path segment $A^p_1A^p_2$ is impossible. Hence, providing the configuration at the point $A^s$, first it is necessary to move the arm from the point $A^s$ to the point $A^p_1$ with the type of configuration to be changed using the values of weighting factors for generalized velocity changes not being equal to unity.

It is also possible to change the type of configuration by fine motions synthesis where the centre of the output link is in the assigned region defined by the parameter $\delta < 10$ mm [9]. The use of the third component of the knowledge base $\Psi_3$ is necessary in reducing the calculation time for the vector of generalized velocities where calculated interim configurations intersect the forbidden regions $P_i$ and $P_2$. The vector of generalized velocities $Q_N$ for the case is calculated by the equation:

$$Q_N = Q_M + \sum_{i=1}^{p} k_i m Q_i,$$  

(3)

where $Q_M$ is the vector specifying the point $M^Q \in \Gamma^Q$ conforming with the range of motion minimization criterion [2, 10]. The superscript $^Q$ designates the membership of the geometric object to the five-dimensional space of generalized velocities. The point $M^Q$ prescribes the check point centre connected with the p-plane $\Gamma^Q$; $k_i$ is the coordinates of the point $N_i^Q$ in the p-plane $\Gamma^Q$ (particular instant state of the manipulator mechanism corresponds to each point $N_i^Q$); $m$ is the length of a unit check point segment of the p-plane $\Gamma^Q$, $Q_i$ is unit director vectors of the check point axes, $p$ is the dimension of the p-plane $\Gamma^Q$. For the considered example $p = 2$.

The knowledge base $\Psi_3$ is used to calculate parameter limits $k_i^{max}$ in the relationship (3) for different arm configurations. The array of parameters $\Psi_3$ determines the value of coefficients $a_j^{ni}$ for hyper surface equations which reflect functions $k_i^{max} = f (q_3, q_4, q_5)$ within prescribed ultimate value intervals of generalized coordinates $q_1$ and $q_2$ [12]. The parameters $k_i^{max}$ allow the regions in space of generalized velocities to be specified, these regions assigning the permissible values of vector $Q_N$. These values ensure the prescribed positional accuracy $\delta < 10$ mm of the OL centre.
The algorithm scheme of the android arm motion path synthesis based on the developed knowledge base is shown in figure 3.

Figure 3. Virtual modelling algorithm scheme of android arm motion based on knowledge base

The following notations are taken in figure 3: 1 is the input of arrays data $l_i$, $smi$, $Kod$ and variables $n_k = 0$, $A^i(x^i, y^i)$, $B^i(x_{BC1}, y_{BC1})$, $B^{C12} (x_{BC2}, y_{BC2})$ and $x_t$, where arrays determine: $l_i$ are the lengths of mechanism links, $smi$ are displacements along a coordinate axes, $Kod$ are codes of the coordinate system transformations. Input of array data $Ψ_1$, $Ψ_2$, and $Ψ_3$ specifying the knowledge base of the past experience; 2 is the calculation of via points $A^{P1}$ and $A^{P2}$ specifying the position of a synthesized path for the OL centre point movement, these via points providing the absence of the path and forbidden regions $P_1$ and $P_2$ intersection (provision of minimum offset to forbidden regions); 3 is the determination of parameters specifying icons for projection of arm working envelope $λ^0$ based on the known coordinate points $B^{C1}$, $B^{C2}$ [11]; 4 is the recognition of points $A^s$, $A^{P1}$, $A^{P2}$ and $A^f$ belonging to the working envelop [11]; 5 is the calculation of vector $q_M$ and values $x_s, y_s$ specifying an optimal rest position of the android arm and body (at $U_i = \text{max}$), relative to the manipulation object based on the parameter $z_x$ and array $Ψ_1$; 6 is the analysis of value compliance $q_M$, point coordinates $A^s$, $A^{P1}$, $A^{P2}$, $A^f$, $B^{C1}$, $B^{C2}$ with array values $Ψ_2$, which prescribes deadlock; 7 is the motion synthesis to change the configuration type and determine a new value $q$ [9]; 8 is the calculation of the generalized velocity vector $Q_M(q_{1M}, q_{2M}, ..., q_{nM})$ based on the range of motion minimization criterion on the path sections prescribed by the segments $A^sA^{P1}$, $A^{P1}A^{P2}$ and $A^{P2}A^f$ [2,10]; 9 is the determination of the arm configuration condition assigned by the values and forbidden regions (here the assumption is made that $Δq_i \approx q_{im}$, $q_{im}$ are the components of the vector $Q_M$; 10 is the construction of the next configuration or $q = q + Δq_{im}$; 11 is the determination of maximum values $k_{imax}$ based on $q$ and the array $Ψ_3$ [12]; 12 is the change of values $k_i = k_i + 1$ used in the vector equation (3); 13 are the values $k_i$ satisfying the maximum values $k_{imax}$; 14 is the synthesis of motions with invariant OL centre position [9]. The motion synthesis using weighting factors of generalized velocity values. The arm motion to the type of configuration; 15 is the calculation of the generalized velocity vector $Q_x(q_{x1}, q_{x2}, ..., q_{xn})$ (3) [8]; 16 is the target point reached in the prescribed segment; 17 is the change in the value of the next configuration $n_i = n_i + 1$; 18 is the result output of the motion synthesis along the complete path section determined by the segments $A^sA^{P1}$, $A^{P1}A^{P2}$ and $A^{P2}A^f$.

4. Experimental results

In figure 4 the results of the motion synthesis using the knowledge bases to transfer the manipulation object from the point $A^s$ to the point $A^f$ are shown. In figure 4 the motion synthesis with the type of configuration being changed and using weighting factors of generalized velocities values is shown on the path section prescribed by the points $A^sA^{P1}$. 

![Diagram of android arm motion path synthesis](image-url)
5. Conclusion
The developed algorithm for virtual control of android motion using the developed knowledge bases allows the complex evaluation of current situations to be performed and from this the optimal logic choice to be implemented. Minimal total change of generalized coordinates occurs when making this choice.

The results of computational experiments demonstrate computation time decimation of test assignments related to the putting the manipulation objects on the tool racks and taking them off using the developed knowledge base. The number of cases for motion synthesis resulting in deadlocks is considerably reduced.

The results of the research can be used in developing intelligent control systems of autonomous android robots in the known in advance environment.

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