A Simple Analytical Method to determine the Disposition of a Teleroboting System with two Coordinated Robots

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Abstract

The development of single industrial robot systems in a very well and staticly defined environment reached a very high level. Using robot systems to manage more complicated tasks especially in a dynamically changing environment, one solution will be the use of multi robot systems. In case of a common industrial robot system you have only to take care of a well designed robot oriented environment, that means that you must consider only aspects of workspace, reachability and collision. Besides this spatial point of view you have to describe in case of two robots, which are working together, the coordination in a appropriate way to obtain a good relative disposition of both robots. One possibility frequently used in the past have been experiments with the real robot or simulations to find an appropriate disposition. This method is very expensive in time and money and furthermore not very general, because it is related staticaly to the planed tasks and the experimental environment. Neither this method is very suitable to change the parameters of the disposition dynamically in situ. We have developed a simple analytical method to describe the coordination mathematically using only aspects of the workspace and by making in the second step an optimisation to find the best placement. Because of the availibility of very powerful mathematical programs we can easily deal with the complexity of the equations.

1. Introduction

To increase the capabilities of robots to manage complicated tasks and to enlarge at the same time their possibilities of use, we have to employ multirobot systems. The goal of our project is the development of a robot system for hot line maintenance. The basic hardware of the system consist of a mobil crane with a special designed platform on his top, on which are installed two teleoperated robot systems. Step by step we intend to increase this already functioned basic system by adding a real time imaging system, a user friendly control environment and some more autonomy in form of automatically executed tasks.

To enlarge the flexibility of the work and the reachability in general we foresee a special platform on which we fit the robots movable in well defined directions. Due to this fact we are not only interested in determine the placement uniquely, valid for all the various tasks, but in finding a method that allows us to adapt the disposition of the two robots on special situations. To reduce the mathematical complexity we are making some simplifications by contemplating the workspace of the robots in a two-dimensional way. The implementation of the presented method depends closely on our application but the principle can be surely transferred to other systems.

2. Determination of the parameters

First of all we must specify the parameters which are describing the disposition of the robots. We will introduce now without exact explanations some simplifications concerning the workspace. The workspace of our robot has approximately the geometry of a half sphere. If we define the orientation of the sphere in the world coordinate system like in figure 1.1, it can be showed that is sufficient to contemplate only the plane in xy [CMUEL93].

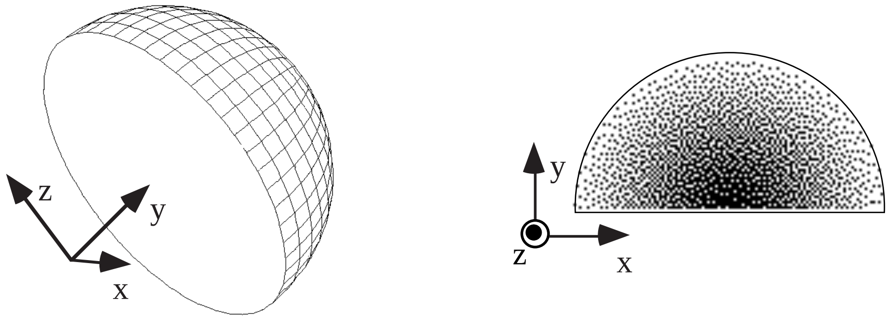

Fig. 1.1: Orientation of the workspace in world coordinates / Sight in xy

Reflecting upon some hardware suppositions as for example the perpendicular mounting of the robots, the dimension of the common and total workspace and some simple aspects of accessibility we can determine the two parameters describing the disposition as the distance d_R and as the angle α. The following figure illustrates some thinking studies. In case (b), for example, the right robot impede the access of the left one and in case (a) would result a great common workspace not suitable for our application, because we don't use the workspace behind robots.

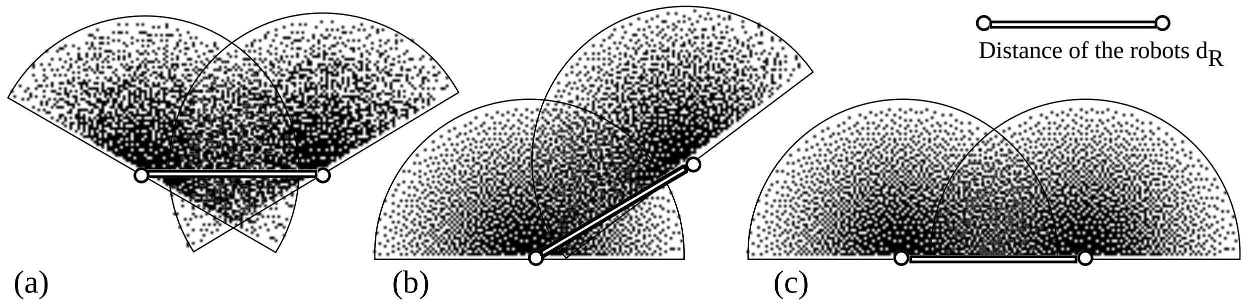

Fig 1.2: Illustration of some reflections to find appropriate parameters

The fact of accessing the objects from the front is exactly the reason why we introduce as a second parameter the angle α. The idea is to decrease common workspace with a low quality for our application and to gain on the other hand on both sides reachability for the single robots. This can be used, for example, to lift up necessary spare parts or to install an automatic tool changer. The two parameters d_R and α are shown in the following figure.

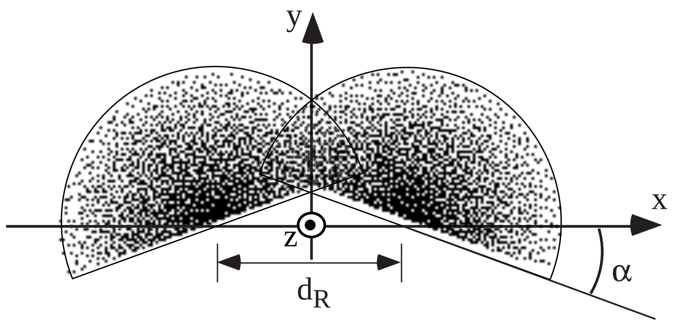

Fig 1.3: Both parameters which represent the disposition

3. Definition of the valuation quantities

Now we have to find some quantities which represent the requirements of our application. They have to be like functions depending of the parameters d_R and α. One way to do this would be to contemplate specific basic actions and to formulate them mathematically. This solution would have the disadvantage that by changing or adding actions you couldn't garantize the validity. Because of that we try to find a description that is not related to special tasks but only to spatial aspects of a generalised action description. This general solution allows the integration of new work techniques and garantize a very flexible use of the system. Using this measures of quality we are able to make an optimisation to determine a good disposition described by d_R and α.

Greatest radius for coordinated two-arm-operations

The great flexibility and suitability of a two arm-system is based in the fact, that it is able to manipulate an object with one arm while supporting with the other the manipulation. Because of security aspects in high voltage areas we had to maximize the distance to the point which can be reached by both arms at the same time. Supposing here that the dimensions of the handled object is nearly equal to the size of the gripper, we can easily formulate r_{coord}, which depends only from d_R (see fig. 2.1).

$$r_{coord}(d_R) = \sqrt{r^2 - (d_R/2)^2} \qquad (2.1)$$

Greatest width in the distance r_{coord}

Defining r_{coord} we have postulate the restriction that the objects have small dimension. For our application, however, we utilise like hot line tools very often sticks and line hoses which have strong extension in some directions. Also here we had to handle in a distance as great as possible. Referring at the geometric situation in fig. 2.1 we can define the value d_{byp} in the following way.

$$d_{byp}(d_R) = 2 \cdot d_R \qquad (2.2)$$

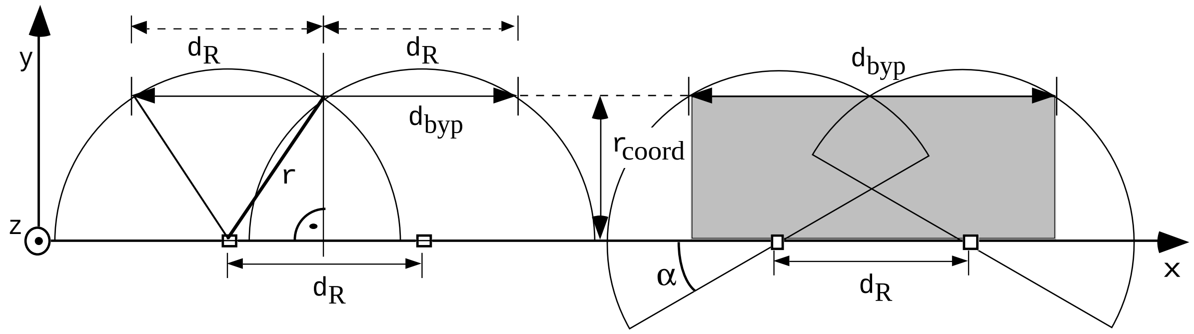

Fig 2.1: Sketch of d_{byp} and r_{coord}

For the evaluation, we don't have consider yet the distance r_{coord} in d_{byp}. Therefore we take as the quantity to be maximise the area that will be formed by a rectangular with the sidelength d_{byp} and r_{coord} [see darked area in fig 2.1]. It's obvious that this area is a measure for the flexibility of manipulations with great objects.

$$d_{eff}(d_R) = 2 \cdot d_R \cdot r_{coord} \quad (2.3)$$

COMMON WORKSPACE

For the flexible coordinate handling of object (small dimensions!) it is important to maximise the workspace reachable by both arms simultaneously. This workspace can be calculated by the intersection of the two single workspaces. In our case of a two-dimensional contemplation, the intersected area F_{coord} can be calculated to:

$$\begin{aligned} F_{coord}(d_R,\alpha) = {} & (r^2 \cdot \arccos\left(\frac{d_R}{2r}\right) - \frac{d_R}{2} \cdot r_{coord}) \\ & - r^2 \cdot (\alpha - \sin\alpha \cdot \cos\alpha) - 0{,}5 \cdot (2r\cos\alpha - d_R)^2 \cdot \tan\alpha \end{aligned} \quad (2.4)$$

TOTAL WORKSPACE

A great total workspace implies a high reachability of objects and due to fewer moving of the platform it determine how fastly and flexibly we can realise the tasks. Since we have already find an expression for F_{coord}, we can easily formulate the quantity F_{tot}:

$$F_{tot}(d_R,\alpha) = \pi \cdot r^2 - F_{coord}(d_R,\alpha) \quad (2.5)$$

The next figure shows the geometry of the quantities F_{tot} and F_{coord}, which was described above. We renounce at this place on a detailed explanation of the used geometrical formulas.

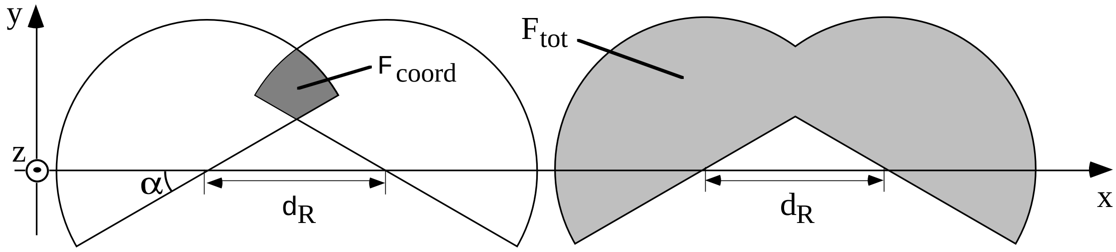

Fig 2.2: Sketch of F_{coord} and F_{tot}

After having defined the valuation quantities we must determine the range of the parameters d_R and α. d_{Rmax} is limited by the validity of the mathematical equations

(d_{Rmax}=2r cos α_{max}) and d_{Rmin} by hardware limits because of a collision of the two robots. In case of α we fix the range intuitively to $\Delta\alpha \in [0, \pi/8]$. Greater values of α don't make sense due to a too strong decrease of common workspace.

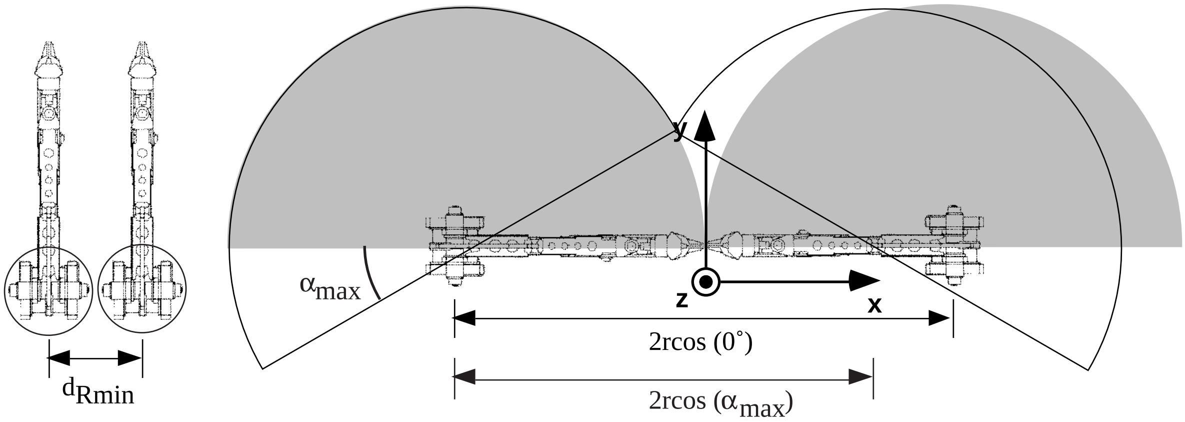

Fig 2.3: Illustration of the parameters ranges

4. Summing the quantities

The goal of our contemplation is to find a disposition, where all of the four values are as high as possible. Therefore we have to sum the four equations in a appropriate way and search then the maximum of this function.

First of all, because the range and the dimensions of the values are quite different, we will normalise them, so that their common range of values is between 0 and 1. The normalised functions $d^*_{eff}(d_R)$ and $r^*_{coord}(d_R)$ are shown in the following figure 4.1. The functions $F^*_{coord}(d_R, \alpha)$ and $F^*_{tot}(d_R, \alpha)$ depend of two parameters and we have to make a three-dimensional visualisation (see fig. 4.2).

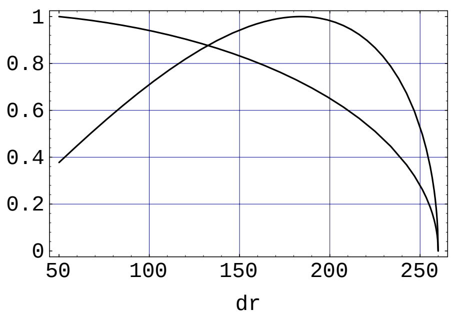

Fig 4.1: Function plot of normalised d_{byp} and *rcoord*

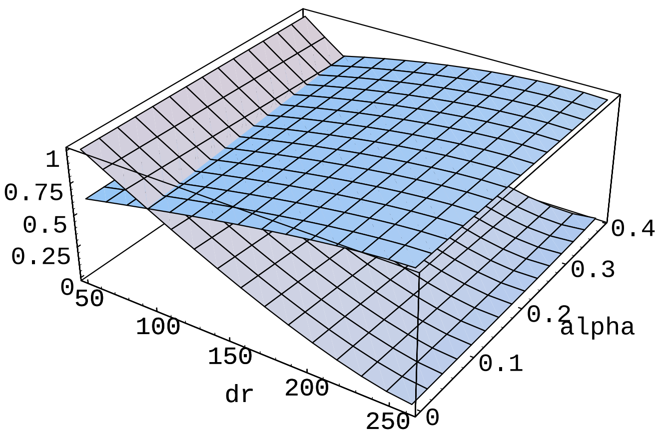

Fig 4.2: 3D-function plot of F_{coord} and F_{tot}

After having normalised the function, the question is now, how we sum the equations. Usually for an optimisation you sum up the single equations. Although we would obtain with this method a mathematic expression much more easily to handle, we decide to multiply the functions.

$$val_{\Pi}(d_R, \alpha) = d^*_{eff}(d_R) \cdot r^*_{coord}(d_R) \cdot F^*_{tot}(d_R, \alpha) \cdot F^*_{coord}(d_R, \alpha) \quad (4.1)$$

In (4.1) all the values affect val with the same weight or lets say importance. The single values represent various classes of actions. It is probable, that, to perform the work, the single actions are distributed quite inequally, in order that is would be useful to accentuate or to weigh the particular quantities differently. By introducing the exponents κ_1 to κ_4 we are able to adapt the equations to the performed task. The function modified this way is:

$$val_{\Pi}(d_R,\alpha) = {d^*_{eff}}^{\kappa_1}(d_R)\cdot {r^*_{coord}}^{\kappa_2}(d_R)\cdot {F^*_{tot}}^{\kappa_3}(d_R,\alpha)\cdot {F^*_{coord}}^{\kappa_4}(d_R,\alpha) \quad (4.2)$$

To explain the fact of multiplying the equations we will make some thinking studies. In case of summing up the values we would obtain a function

$$val_{\Sigma}(d_R,\alpha) = \kappa_1\cdot d_{eff}(d_R) + \kappa_2\cdot r_{coord}(d_R) + \kappa_3\cdot F_{tot}(d_R,\alpha) + \kappa_4\cdot F_{coord}(d_R,\alpha). \quad (4.3)$$

Function 4.3 shows with equally weighed exponents *(κ_1 = 2; κ_i = 1 ; i = 2…4)* a maximum that is comparable with the maximum we obtain by the equation 4.2. The great difference is, that already in case of small variation of the weights *($\Delta\kappa$=1)*, no sensible maxima are produced. This happens because small values can't influent the quality function in an appropriate way. It is obvious, that a linear weighting fails, because we have to weight small values more strongly than great values. This is exactly that what result in case of a multiplication. To illustrate this we make the following contemplation. We suppose now the quality function like

$$val_{\Pi}(p) = \prod_{i=1}^{4} {x_i}^{\nu_i}(p). \quad (4.4)$$

Furthermore we define *$val^*(p)$* as the logarithm of the quality function *val(p)*. Due to the logarithm is increasing monotonously in the range 0..1, the maxima will be at the same position. Here we can neglect the different characteristic of the function, because we are only interested in the position of the maximum.

$$val^*(p) = \ln\left(\prod_{i=1}^{4} {x_i}^{\nu_i}(p)\right) \quad (4.5)$$

Exploiting the special property of the logarithm we can transform the product 4.5 in a sum

$$val^*(p) = \sum_{i=1}^{4} \nu_i \ln(x_i(p)) \quad (4.6)$$

To determine now the position of the maximum, we have to differentiate 4.6 in *p* and to solve the following equation:

$$\left(val^*(p)\right)' = \sum_{i=1}^{4} \nu_i \cdot \frac{1}{x_i(p)} \cdot x_i'(p) = 0 \quad (4.7)$$

In 4.7 we can see very well, that small function values *$x_i(p)$* will be weighted more due to the factor $(x_i(p))^{-1}$. This is exactly that, what we intended.

Now we can return to the function *val(d_R,α)*, given in (4.2), which is plotted in figure 4.3 for *κ_i = 1 ; i = 1…4*. We can determine the position of the maximum analytically, numerically or, avoiding the complexity of the calculations, more simpler graphically.

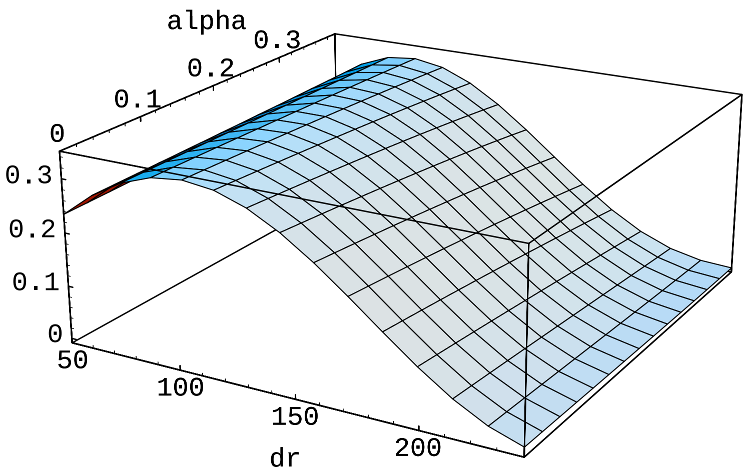

Fig. 4.3: Quality function $val(d_R,\alpha)$

We can determine the best disposition in case of $\kappa_i = 1 ; i = 1\ldots4$ and $r=130cm$ to

$$\alpha = 0 \quad ; \quad d_{Ropt} = 104{,}2\,\text{cm} .$$

By variating the values of κ_i we find out, that only with a very high weight on the total workspace $(\kappa_3 \geq 7)$, would result a value of α that is different to zero. But even in this case the maximum isn't very distinct, that we can fix the value of α to zero and simplify the calculations considerably. The following table shows how various values of $\kappa_i ; i = 1\ldots4$ have an effect on the parameter d_R and the valuation quantities. d_{Ropt}, r_{coord} and d_{byp} are given in centimetres while F_{coord} and F_{tot} are given in square metres.

κ_1 (d_{eff})	κ_2 (r_{coord})	κ_3 (F_{tot})	κ_4 (F_{coord})	d_{Ropt}	r_{coord}	d_{byp}	F_{coord}	F_{tot}
1	1	1	1	104,3	119,1	208,5	1,34	3,97
2	1	1	1	128,4	113	256,8	1,06	4,25
1	2	1	1	96,76	120,7	193,5	1,43	3,88
1	1	2	1	117,2	116	234,5	1,18	4,13
1	1	1	2	73,93	124,6	147,9	1,71	3,6
1	2	1	2	70,55	125,1	141,1	1,75	3,56

Due to the similarity to the man's shoulder-arm-system and the similar kinematic situation we are trying to compare the results with the anthropromethic measures of a 5th percentile-man [DIN85]. The proportion shoulder-width to arm-length of the man is given to 0,546. With this arm-length as r of the robot, d_R of our robot-system should be 70,98 cm. The difficult question now is, how we fix the values of the weights $\kappa_{i,}$ to model approximately the human situation.

In any case we can give the a higher importance to coordinatly done work and weight twice the values representing the coordination. In the table above we find then $d_R=70{,}55cm$.

This comparison technical system/human anthropometry isn't valid in a quantitative way due to the simplifications and the remaining kinematic differences but anyway the results seem to confirm our method. The following figure shows the anthropromethic dates of a 5th percentile-man.

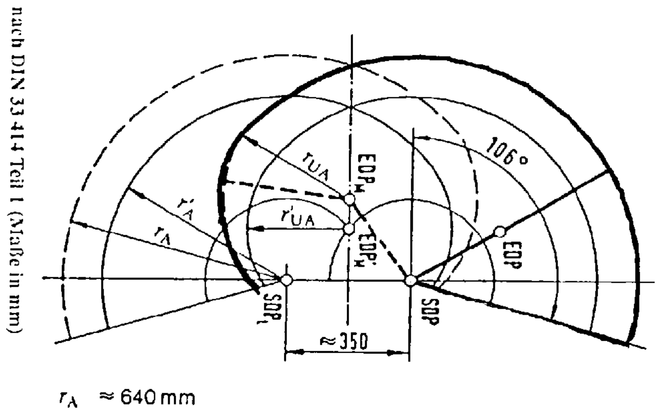

Fig. 4.4: Reachable area of a 5th percentile-man

5. Summary

The showed method can be adapted to nearly any other application of a multi-robot-system. In our case with four quantities, the mathematic complexity to find the position of the maximum was quite easy to manage. But if we define more valuation quantities and increase the accuracy, it could be useful to determine the maximum using genetic algorithms.

6. Reference

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