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Concept of Uncertainty Developed in a Vertical-Axis Robot Arm

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ABSTRACT

This paper deals a review of the uncertainty modeling in the placement of work space fixtures, say a container in the work space environment of the robot to do a particular task, i.e., to insert or remove some of the manufactured components from the bin or the container. The uncertainty model shown in this paper makes a compromise between the optical distortion using a camera and the robot precision and gives a optimal distance for the container to be placed.

Keywords: *Robot, Uncertainty, Optical distortion, Precision, Workspace fixture, Camera.*

1. INTRODUCTION

The problem of planning under uncertainty has received significant attention in the scientific community over the past few years. It is now well recognized that considering uncertainty during planning and decision-making is imperative to the design of robust computer systems. This is particularly crucial in robotics, where the ability to interact effectively with real-world environments is a prerequisite for success [2]. Uncertainty in robot task planning is concerned with knowing the exact position and orientation of the objects / parts being manipulated in the external environment of the robot. Uncertainty always occurs when a robot is being made to do a particular task, i.e., say, to reach to the point n and after running the program to reach that particular point n, it may just reach very near to the point n or slightly ahead of point n. This is what is called as uncertainty or error [3]. The robot is not certain (not sure) that it will reach that particular point n. This is because of the various non-linearities that are present in the robotic system such as tolerances, backlash / freeplay in the gears, weight of the system, mass, inertia, hysteresis, positional errors, friction, damping, dead zone, saturation, resistance, etc. Uncertainty is very important in task planning of robots, because it reduces the positional accuracy of the system [1].

The paper is organized in the following sequence. A brief introduction about the work in the paper was given in the previous paragraphs. The section 2 gives information about the uncertainty in robots. Section 3 gives the information about the illustration of uncertainty in robots using a example based case study. Section 4 discusses about the modelling of uncertainty. This is followed by the conclusions in section 5 and the references.

2. UNCERTAINTY IN ROBOTS

A robot is nothing but a manipulation device, i.e., it is used to do some useful work (welding, painting, drilling, buffing, grinding, etc.. or do the pick and place action). Even when the exact position and orientation of the objects / parts / payloads that are to be picked up within the workspace is known and is given as input to the task planner, the task planning is still a challenging problem, because it has to take care of so many sub-problems such as the obstacles, other objects in the work cell, the non-linearities etc. and there may be certain error at the final point [4] [10].

Therefore, in uncertainty, the variables which represent the exact position and the orientation of the parts / objects will have a nominal value (approximated value / nearest value) plus an error term Δv which is known as uncertainty or the tolerance band. The exact position and orientation of the part which are represented by exact variables is the sum of the approximated value or the nominal value of the variable of the position and the orientation of the part + the tolerance (error term) or the uncertainty which is given by the equations (1) to (4). Two types of uncertainty exists, viz., velocity uncertainty and the positional uncertainty [10], [5].

$$v^{exact} = v^{nominal} + \Delta v \qquad \text{Eq}^n \ (1)$$

$$\| \Delta v \| \le \Delta v^{max} \qquad \text{Eq}^n \ (2)$$

$$p^{exact} = p^{nominal} + \Delta p \qquad \text{Eq}^n \ (3)$$

$$\| \Delta p \| \le \Delta p^{max} \qquad \text{Eq}^n \ (4)$$

where, v^{exact}, p^{exact} are the exact values of the velocity and position which are represented by exact variables, $v^{nominal}$, $p^{nominal}$ are the nominal value or the nearest (approximated value) of the velocity and position and Δv is the error term or the uncertainty, i.e., the difference between the exact and the nominal value of the variables or the tolerances. For example, if a command is given to the robot to move at 10 cms / sec, it will not move at 10 cms / sec, but it will be moving at 9.9 cms / sec. ± 0.1 is the uncertainty or the tolerance band [6], [10].

Exact value (10 cm / sec) = nominal value or nearest or approximated value (9.9 cm / sec) ± uncertainty (± 0.1). Uncertainty is similar to the tolerance in resistances. The last ring on the wire wound resistors is the tolerance band, i.e., if we take a 1 KΩ resistor and measure it with a multimeter, its value will not be exactly 1000 Ω. It may be 995 Ω or 1005 Ω. The last rings present on the resistor are the tolerance bands. Hence, uncertainty in our knowledge of the exact position and orientation of the tool produces uncertainty in the final configuration of the manipulated part [7] [10].

Even, if we use a highly sophisticated vision system or any other method of sensing, it is very difficult to know the exact position and orientation of the part or the objects external to the robot; since, the objects are three dimensional in nature. Since, exact values of the parameters for the part variables are not known by any method of sensing, the robot task planning technique must be done using the nominal values and the error bounds [8] [10].

Most approaches for robot planning and control assume there is a known model that quantitatively describes the robot's dynamics and sensors, as well as other agents and the environment. This is convenient when available, and solutions have been produced for large-scale high-dimensional domains using a wide variety of algorithms [9]. However these methods are severely limited in applications where writing down the exact model is time-consuming and error-prone, or when the model changes over time. A number of ad-hoc approaches are available for dealing with this, often involving re-planning. However the model uncertainty is not generally considered as an integral part of the initial planning and control algorithm [24] [10].

3. ILLUSTRATION OF UNCERTAINTY USING AN EX

Let us illustrate how uncertainty affects / influences robot task planning using an example. Consider a cylindrical coordinate robot and its work-cell with a overhead camera which is used to sense the various parts and other devices as shown in Fig. 1. Consider the problem of deciding where to place a part fixturing device (container) in the work space w.r.t. the robot base. Let us keep the part fixturing device at a point 'f' on the work surface of the robot and the overhead camera at a radial distance of r_c from the base of the robot and at a certain height of Δp_0 above the work surface from the robot base which represents a distance of r = 0. The main aim of planning the layout of the workstation is to do some manipulation task, i.e., to insert and remove the manufactured parts from the work surface by accurately placing the tool-tip p at a fixture point 'f' [10].

4. MODELLING OF UNCERTAINTY

For a cylindrical coordinate robot, we have [11] [10]. Let us define the following terms

Δϕ = Base joint angular precision (revolute),

Δz = Vertical extension joint precision (prismatic),

Δr = Radial extension joint precision (prismatic),

The overall precision Δp is divided into horizontal component Δh and vertical component Δv. The horizontal precision is divided into radial precision Δr, which is uniform and angular precision about the base r Δϕ, which is varying. If the arm moves by a small angle Δϕ, r is the radius of the cylinder at any instant, then the radial precision is given by Δr and the angular precision about the base is given by r Δϕ. Then, overall horizontal precision is given by [10]

$$\Delta h = \sqrt{(\Delta r)^2 + (r\,\Delta\phi)^2} \qquad Eq^n\ (5)$$

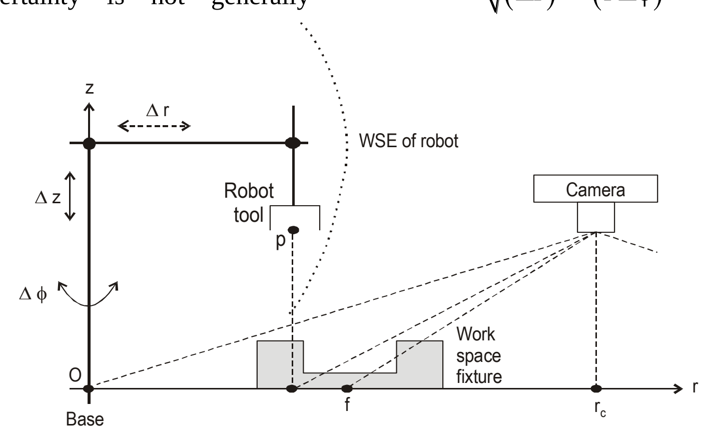

Fig. 1 How to plan the layout of the work station of a robot

The horizontal precision is the highest along the inside surface of the WSE and lowest along the outside surface. When the tool is fully towards the base, the precision is the highest and when the tool is fully extended, the precision is the lowest, i.e., the horizontal precision goes on decreasing as the arm starts moving out radially from the base. The vertical precision is given by Δv which is Δz and is uniform (since prismatic motion). If Δr is the radial precision, Δh is the horizontal precision and Δz is the vertical precision of the robot, then, the total or the overall precision of the cylindrical coordinate robot for positioning the tool-tip 'p' is given by the robot precision uncertainty model in equation (6) as [10]

$$\Delta p^{robot}(r) = \sqrt{(\Delta r)^2 + (r\,\Delta\phi)^2 + (\Delta z)^2} \qquad Eq^n\ (6)$$

Thus, from the Eq^n (6), we can come to a conclusion that if the workspace fixture or the container is placed on the boundary of the workspace envelope, then the precision is the worst [37]. If the workspace fixture is placed near to the base of the robot, then the precision is the highest [11] [10].

Many a times, the location of the part fixturing device is not at all known directly [36] ; but, is instead known using the observations from an overhead camera, i.e., the vision system can be used to know the details of the location and orientation of the part fixturing device [13]. By using similar triangles inside and outside the vision system, the horizontal distance of the part fixturing device from the camera is directly proportional to the vertical distance between the camera lens and the part fixture. i.e., from the diagram it is r_c f [12] [10]

Then, we must raise the part fixture as much as possible in addition to placing it near the robot, i.e., on the periphery of the work envelope of the robot. When we raise the fixture, it will be located along the outer periphery of the viewing area of the camera, since the camera lens catches the image of the object, which is placed in the workspace fixture in a 120° cone angle. If the part fixture is placed at the periphery of the viewing area of the camera, then the images will be distorted, since the image of the part fixture is captured by the camera in a side view [14] [10].

The effect is more when a very wide-angle lens such as a fish eye is used. That is, there is optical distortion, the images will be distorted when viewed from a side or an angle and the sharpness at the edges will be very very less [38], because of the presence of shadows. This is similar to reading of an ammeter or voltmeter. In order to represent the optical distortion of the image, the following uncertainty model of the camera is used, i.e., from the robot base, the position of the camera is given by the camera uncertainty model in equation (7) as [15] [10]

$$\Delta p^{camera}(r) = \Delta p_0 + \alpha\,(r - r_c)^2 \qquad Eq^n\ (7)$$

First term → Represents the constant error associated with the fact that resolution of the image is finite [30].

Second term → Represents the distortion in optics and is function of square of the distance [31].

Δpcamera(r) → Represents the position of the camera as a function of 'r', the radial distance, i.e., the uncertainty due to optical distortion [32].

α → Positive constant [33].

r_c → Radial position of the camera from the robot base [34].

Δp_0 → Position of the camera (placed at a certain vertical height from work surface) [35] [10].

If the objects / parts that are to be manipulated and the work space fixture is kept on the outer periphery of the viewing area of the camera, i.e., on the outer periphery of the work space envelope, then, naturally, the images will get distorted as well as precision is very low. If the workspace fixture is kept exactly below the camera, then optical distortion = 0 (∵, $r = r_c$), but the precision is the worst (∵, the WSF is at the outer periphery of the WSE) [16]-[18] [10].

If the workspace fixture is kept at the base of the robot, then optical distortion is very high (∵, WSF is kept at the corners of the viewing area of the camera), but the precision is the best (∵, the WSF is towards the inner surface of the WSE). Therefore, according to the camera precision equation (7), in order to minimize the camera error or the error in the image, the part fixture should be placed directly below the overhead camera and according to the equation (6), the part fixturing device should be placed as close to the robot in order to have very high precision and to minimize the manipulation error.

Therefore, the two equations (6) & (7) have to be solved simultaneously in order to find an optimal position r_{opt} for the part fixture to be placed [19]. In the optimal radial position $r_{opt,}$ the precision is also good as well as optical distortion is also satisfactory. In that position the part fixture should be placed, i.e., the camera placement should be above or slightly ahead of the work envelope of the robot and the part fixture should be just below the tool tip [20]. The solution of the two equations, which are solved simultaneously, is displayed graphically as shown in the Fig. 2 [39] [10].

From the Fig. 2, we can come to a conclusion that, the most optimal radial position for keeping the part fixturing device on the work surface is given by $r_{opt.}$ This position lies somewhere between the camera which is placed at $r = r_c$ and the robot base $r = 0$. If the radial precision Δr and the vertical precision Δz of the cylindrical coordinate robot are very small; then, they can be neglected. Therefore, the Eq^n (6) for the overall precision of the robot can be approximated as [21] [10]

$$\Delta p^{robot}(r) = \sqrt{(\Delta r)^2 + (r\,\Delta\phi)^2 + (\Delta z)^2}$$

$$\Delta p^{robot}(r_{opt}) \approx r\,\Delta\phi \qquad \text{Eq}^n\ 8\ (a)$$

Similarly, the camera precision model can be approximated as [22]

$$\Delta p^{camera}(r) = \Delta p_0 + \alpha\,(r - r_c)^2$$

$$\Delta p^{camera}(r_{opt}) = \Delta p_0 + \alpha\,(r_{opt} - r_c)^2 \qquad \text{Eq}^n\ 8\ (b)$$

Under these conditions, when $r = r_{opt}$, the two equations 8(a) and 8(b) can be equated [29] [10].

$$\Delta p^{robot}(r_{opt}) \approx \Delta p^{camera}(r_{opt}) \qquad \text{Eq}^n\ 9\ (a)$$

$$r_{opt}\,\Delta\phi = \Delta p_0 + \alpha\,(r_{opt} - r_c)^2 \qquad \text{Eq}^n\ 9\ (b)$$

Therefore, the approximate value for the optimal radial position of where the part fixturing device should be placed on the work surface can be computed by solving the Eq^n 9 (b) [23].

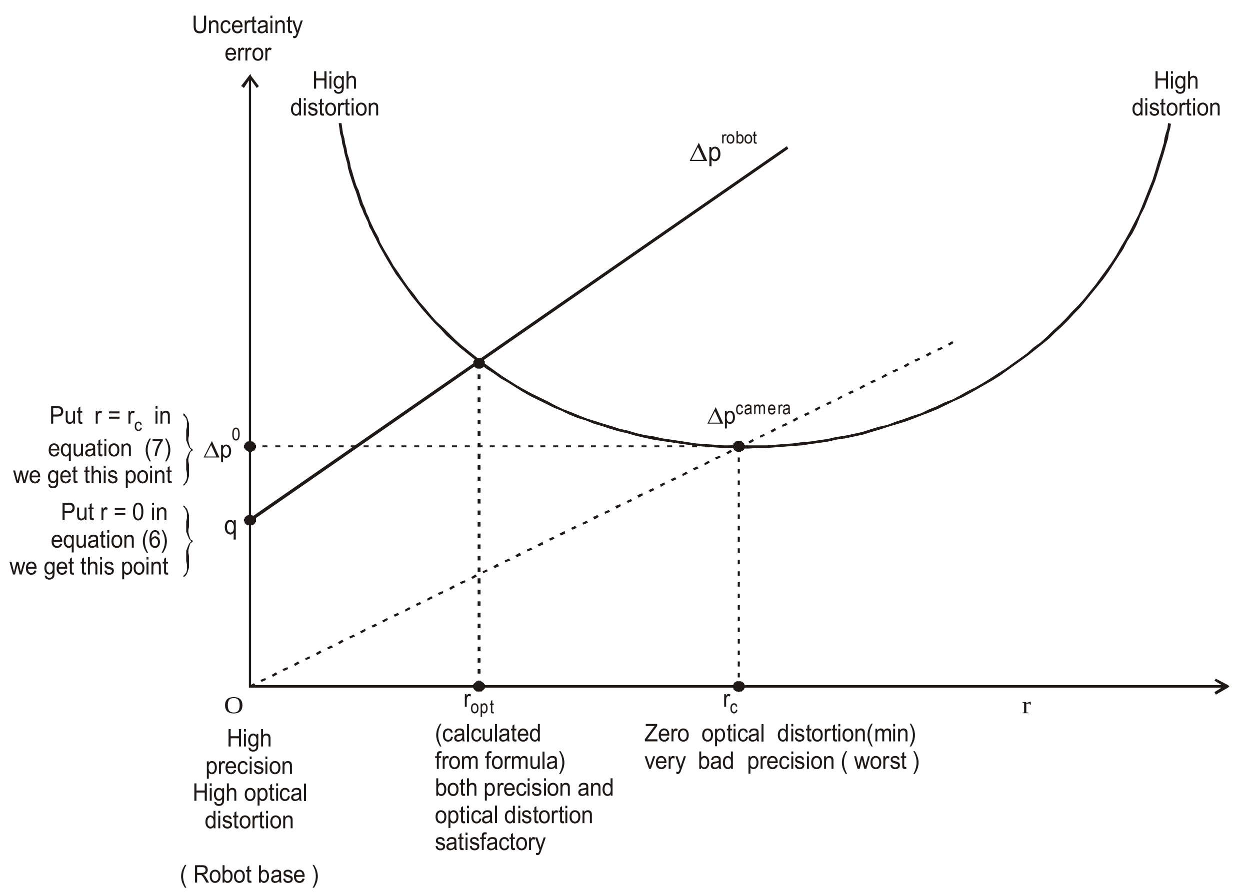

Fig. 2 : To determine the optimal position for the placement of the workspace fixture in the workspace of robot

$$r\,\Delta\phi = \Delta p_0 + \alpha\,(r - r_c)^2 \qquad \text{Eq}^n\ (10)$$

when

$r = r_{opt}$; we get ,

$$r_{opt}\,\Delta\phi = \Delta p_0 + \alpha\,(r_{opt} - r_c)^2$$

$$\Delta p_0 + \alpha\,(r_{opt} - r_c)^2 - r_{opt}\,\Delta\phi = 0$$

$\alpha\,(r_{opt} - r_c)^2 - r_{opt}\,\Delta\phi \;+\; \Delta p_0 \;=\; 0$

Solving this quadratic equation, we get the optimal value of 'r' by solving the two equations as [10]

$$r_{opt} \approx \frac{(2\alpha r_c + \Delta\phi) - \sqrt{(2\alpha r_c + \Delta\phi)^2 - 4\alpha\{\Delta p_0 + \alpha(r_c)^2\}}}{2\alpha} \qquad Eq^n\ (11)$$

From the Fig. 2 for determining the optimal fixture position, we can see that the optical distortion is the highest at the ends of the curve, i.e., on either sides of the point $r_{c,}$ since the error (optical distortion) is proportional to the square term [28]. Since, r = 0 corresponds to the origin of the coordinate system or the centre of the robot base, putting r = 0 in the Eq^n (6), we get [24]

$$\Delta p^{robot}(r) = \sqrt{(\Delta r)^2 + (r\,\Delta\phi)^2 + (\Delta z)^2} \qquad Eq^n\ (12)$$

$$r = 0 \Rightarrow \Delta p^{robot}(r) = \sqrt{(\Delta r)^2 + (\Delta z)^2} = q \qquad Eq^n\ (13)$$

which is shown as the point q on the vertical axis [10].

At this point, the precision is very high and the optical distortion is also very high. As the radial distance 'r' from the robot base goes on increasing, the optical distortion error goes on decreasing and when the position of the overhead camera is at $r = r_{c,}$ the Eq^n (7) will be reduced to [25] [10]

$$\Delta\,p^{camera}(r) = \Delta p_0 + \alpha\,(r - r_c)^2$$

$$r = r_c \Rightarrow \Delta\,p^{camera}(r) = \Delta p_0 \qquad Eq^n\ (14)$$

which is the exact position of the overhead camera for minimum optical distortion (WSF just below the camera), but the robot precision goes on decreasing.

Thus, after making an optimization [26] about the WSF position, we can see that ropt is the point where the work part fixture is to be placed, i.e., somewhere in between the robot base and the camera at $r = r_c$. At this point, errors are also very less and optical distortion of the images is also quite satisfactory as well as precision is also quite satisfactory [27] [10].

5. CONCLUSION

The uncertainty model for the optimal placement of the robot fixture in the workspace of the robot was dealt with in this paper. Finally, the optimal placement for the fixture was shown to be r_{opt} which was obtained by solving the 2 equations. In this position, if we keep the WSF, the precision and the optical distortion are both satisfactory [10].

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Dr. T.C.Manjunath was born in Bangalore, Karnataka, India on Feb. 6, 1967 & received the B.E. Degree (Bachelor of Engg.) from R.V. College of Engg. (Bangalore Univ.) in the year 1989, M.Tech. degree in Automation, Control & Robotics from the Govt.'s L.D. College of Engg. (Gujarat Univ.) in the year 1992 and Ph.D. in Systems & Control Engg. from the prestigious Indian Institute of Technology Bombay (IIT Bombay) in the year 2007 respectively. He has got a teaching experience of more than 23 long years in various engineering colleges all over the country (Karnataka, Gujarat, Maharashtra) and is currently working as **Principal** in **HKBK College of Engg.**, Bangalore, Karnataka, India. He has also worked as a Project Assistant and as a Research Engineer in the Systems and Control Engineering (IIT Bombay, India) and worked on control of space launch vehicles using FOS feedback technique in IITB. He has published a number of papers in various National, International journals and Conferences in India & abroad and published more than a **dozen textbooks**, notable among them being on Robotics, first one being Introduction to robotics, second one which has gone upto the fourth edition, titled, 'Fast Track to Robotics' and the third one, which has gone upto the fifth edition, titled, 'Fundamentals of Robotics' in 2 volumes, Vol.-1 and Vol.-2 along with a CD which contains about 200 C / C++ programs for performing various simulations on robotics. He has also published a research monograph in the International level from the Springer-Verlag publishers based on my Ph.D. thesis topic titled, "Modeling, Control and Implementation of Smart Structures", Vol. 350, LNCIS, costing **114.95 Euros**. He is a member of IEEE for the past 12 years, SPIE student member and IOP student member for 4 years, life member of ISSS (India), life member of the ISTE (India), life member of

ISOI (India), life member of SSI (India), life member of the CSI (India), Sr. Member of IACST (Singapore) and life member cum fellow of the IETE (India). He has also presented a number of guest lectures and seminars in many institutions across the country and participated in more than 2 dozen CEP / DEP courses, seminars, workshops, symposiums and also conducted a few courses in the institutions where he has worked. He was awarded with the "Best research scholar award in engineering discipline" for the academic year 2006-07 from the Research Scholars Forum (RSF) from Indian Institute of Technology Bombay (IITB). This award was presented in recognition of the significant contribution to the research (amongst all the researchers in all disciplines) in IIT Bombay. Also, he was conferred with the best paper awards in a number of conferences. he was also instrumental in getting Research centres along with M.Tech programs in the colleges where he has worked so far. He was also responsible for getting AICTE grants under MODROB scheme for the development of the Robotics & Mechatronics Labs. Apart from which, he has brought a number of grant-in-aids for the conduction of various events like workshops, conferences, seminars, projects, etc, wherever he has worked. He has visited Singapore, Russia, United States of America, Malaysia, Taiwan, Japan, Canada, Nepal and Australia for the presentation of my research papers in various international conferences. His biography was published in 23rd edition of Marquis's Who's Who in the World in the 2006 issue. He has also guided more than 3 dozen projects (B.Tech. / M.Tech.) in various engineering colleges where he has worked so far, apart from guiding a couple of research scholars who are doing Ph.D. in various universities under his guidance. Many of his guided projects, interviews, the events what he had conducted have appeared in various national newspapers and magazines. He has also reviewed many research papers for the various national & international journals & conferences. He has also organized a number of state & national level sports tournaments like yogasana, chess, cricket, etc. He is also an editorial board / advisory board / reviewer member on many of the national & international Journals. He has also served on the advisory / steering / organizing committee member of a number of national & international conferences. He has given many keynote / invited talks / plenary lecturers in various national & international conferences and chaired many sessions, was the judge & was the chief guest on various occasions. He has given a number of guest / expert lectures in various colleges across the country. He has also conducted / organized / convened / coordinated more than 4 dozen courses / workshops / technical paper fests, Student level competitions, etc., in various engineering colleges where he worked so far