ROBOTICS

Prof. P.Seshu
Department of Mechanical Engineering
IIT Bombay

Lecture No-12

Trajectory Planning Time(1:19 min)

Okay so in todays class and couple of lectures that follows we will be talking a topic called a trajectory planning (Ref Slide time 01:31 min)

what we have so for learned about the various aspects of robotics is the different type of robotic configuration of robotics that are used different types of applications in which robots are used different mechanism that are used the various elements that transmits motion from the individual a joint activators to the end effectors that carries the tools that does the useful task for you in the last class so we have looked at the various types of activators and also the sensors the integral part of the any robot okay so we have covered those aspects so far in the current discussion we will look at the trajectory planning what we mean by trajectory planning and how we actually achieve it will consume as for the next couple of hours

if you look at the typical robot you have probably looked at the stationary robotic manipulator that essentially does a task of picking up of object pick and place kind of device supposing i have a object here okay i want to just pick it up and keep it here this could be my task repeatedly i do it from it could be stationary pin to another stationary place or it could be on a moving conveyer from a metal handling prospect in this type application you actually looking at where the object is being picked out and where it is to be placed and not really how is the exact specific path that the end effecter creates it in moving from point a to point b okay this is one type of application for which the manipulator could be used but this problem could be slightly more complicated when we talk in term say we are moving here from point a to point b there is a obstacle in it so you would like to go from point a to point b but without colliding with the obstacle so therefore you would like to specify probably as the user of robot manipulator that yes look here you need to go from point a to point b but you would specify certain intermediate point or whatever known as the via points where you are probably executing any specific task you are probably not concerned if it exactly meet the point or does not meet go through the point but you want to be approximately going through the point safer example here i can say that from point a i want to go to point b but via a point c so i want to go roughly like this so that you avoid the obstacle that is the one way where i could specify a path indirectly through initial positions and final positions but avoiding certain obstacles through what is what are known as via path but in this whole process specific path taken between any two point is not of much significance such point are such types of tasks such type of motions or what are known as the point to point motions

so when we will look at the broad issue of trajectory planning differentiate what are the different type of task a robot manipulator will performs and how we generate this types of motion so one category of motion is what is known as the pick and place or point to point type of motion this is typical of a say a material handling or a assembly type of robot but on the other hand supposing i have a thinking of a robot manipulator which does welding on a complex automatic shape okay so the welding gun is held in the robot manipulator end effecter and it has to follow therefore in this case a specific contour where the two part to be join have to be welded together so here this specific path that is taken is a usable path not just the point initial point and the final point but the actual path through which the end effecter path tool moves through is also important so these are known as the continues path of coils so we differentiate between these two different types of motion one is specific kind of motion where the specific path is not of important and the other is the continues path where the specific path through which the object is moving for example the grinding operation after the welding you may want to grind the joint okay the grinding operation these types of operation the end effect continues movement along the path specified path is recovered so we need to look at how we can generate this types of motions how do we planned for this type of motion that will be the topic of the discussion under the head trajectory planning

when we look at the this type of task the gripper or end effecter which is at the tip of the robot manipulator is actually doing the task for you and therefore and it operates in the real world coordinators okay in three dimensional space so when you specify the task which is natural for a user to specify it in terms of the motion of the end effecter tip if there are half a dozen joints which move this end effecters in a coordinator manner let that be so but user really says that the end effecter tip should move in the three dimensional space in this particular manner okay the natural way in which the robot system user task specifications happens is in the terms of a three d space of a end effecter okay

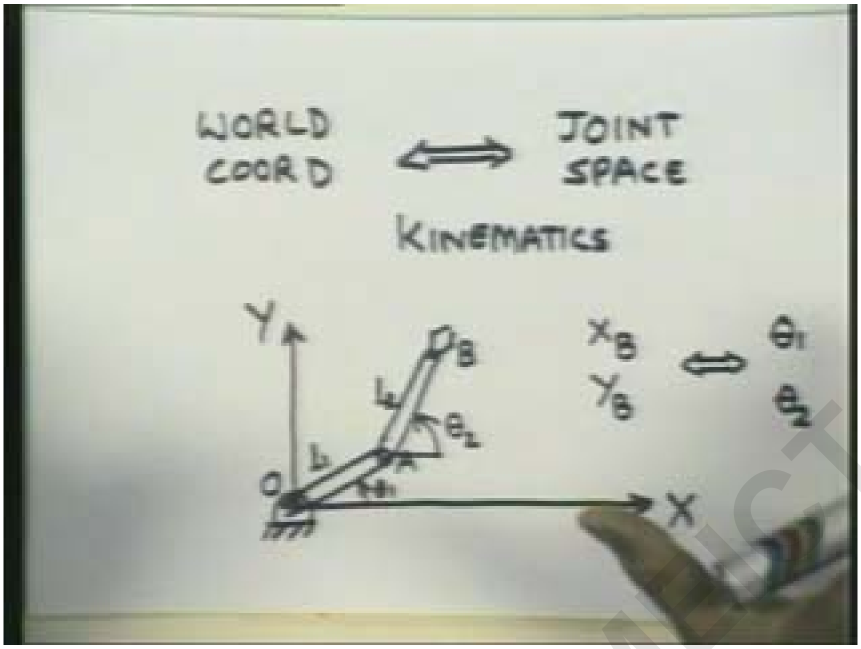
so look at that aspects so the joints natural task specification i would say task specification takes place in terms of the three d space world coordinate okay you are familiar with the world coordinate and the tool coordinate robot coordinate and so on okay so specifying it in terms of the three d space in which the end effecter operates that is natural for the user so if you want to achieve for this kind of trajectory that the user specifies in terms of the end effecter a tip consider the robot to be a the closed loop feedback system therefore if you have some way of sensing in the robot manipulator where you sense the end effecter position its orientation when i say that end effecter move through the certain points okay we always keep in mind that it is not just the position but it is the orientation in which reaches the position it is the velocity with which it moves through the point even the acceleration sometime

okay so all these are implied when we talk in term of end effecter motion so when you are move or decided its path or decided the set of points and the motion through those points which specified by the user natural in world coordinate it is conceivable that you can have some external sensors which keep tracking the end effecter position orientation velocity and joints support keeping it on to the closed loop feedback system so that we will be able to achieve the kind of motion that you want to which it is conceivable

so therefore in such a case the trajectory planning could be entirely done in terms of the motion of the end effecter tip itself but for any robotic manipulator this is not a trivial task even though if something in principle you can think of a robotic manipulator with such external sensors that continuously monitor the end effecters position orientation velocity and so on support it is not trivial task to do this what you have more commonly is that each individual joints each individual degree of freedom an activator which is activating the degree of freedom will typically have a sensor like for example the encoder that you have studied about okay a typical rotary encoder could be mounded on a motor shaft that keeps striking the angular position of the shaft

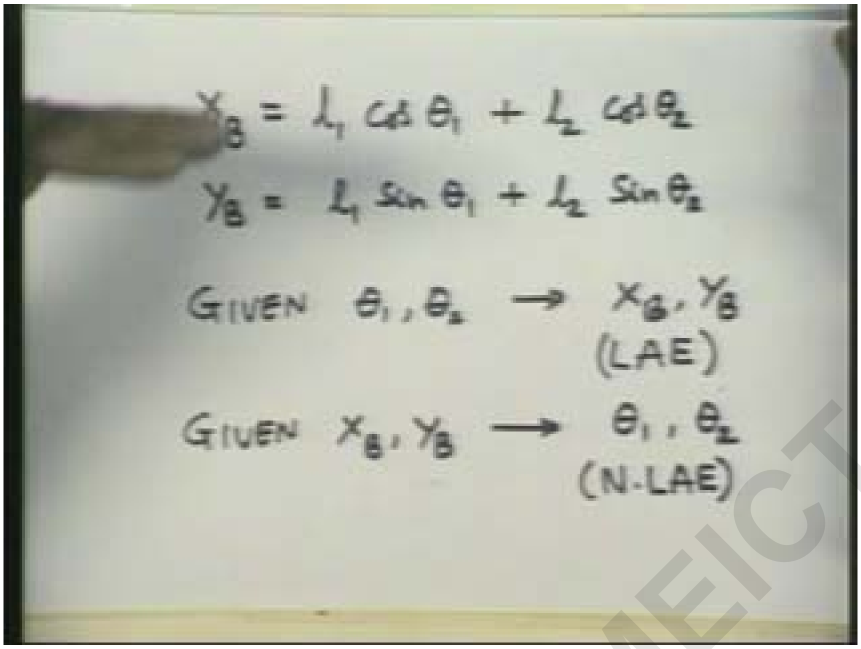
so you know by how much the motor shaft has been the joints moved through as a function of time or similarly you could have a linear encoder that measures the position of a linear vec linear motion continuously with respect to time so for a prismatic join so it is more common that you have sensors at the individuals joints rather than the end effecter tip position so in a closed loop feedback control system that the robot manipulator will is you look at the lower level control being achieved at each individual joint motions rather than actually an end effecter tip position okay so the problem therefore will be that while it is natural for the task to be specified in term of the end effecter world coordinates it is convenient to achieve this through the individual joins motion in a control coordinated manner

so you have to have this type of a mapping which with the end effecter decided motion and the individual joint motion that i need to achieve so that the end effecter moves through that kind of a problem (Ref Slide time 11.09 min)



so we talk in terms of so world coordinate world coordinate to joint space this two need to be map because one natural way to do it for world coordinate for the task to be specified and the motion is in terms of each individual degree of freedom being activated by an activator with some sensors in a closed loop feedback system so these two it would be convenient we can map again of course this are related you are familiar this two are related through the kinematics of the particular configuration in which the robot manipulator is designed okay so you could design you can relates this through the kinematics okay when we say kinematics when we are looking at the geometric relationship between the motions of the individual joints through the linkages that are transmitting the motion from the individual joints to the effecter

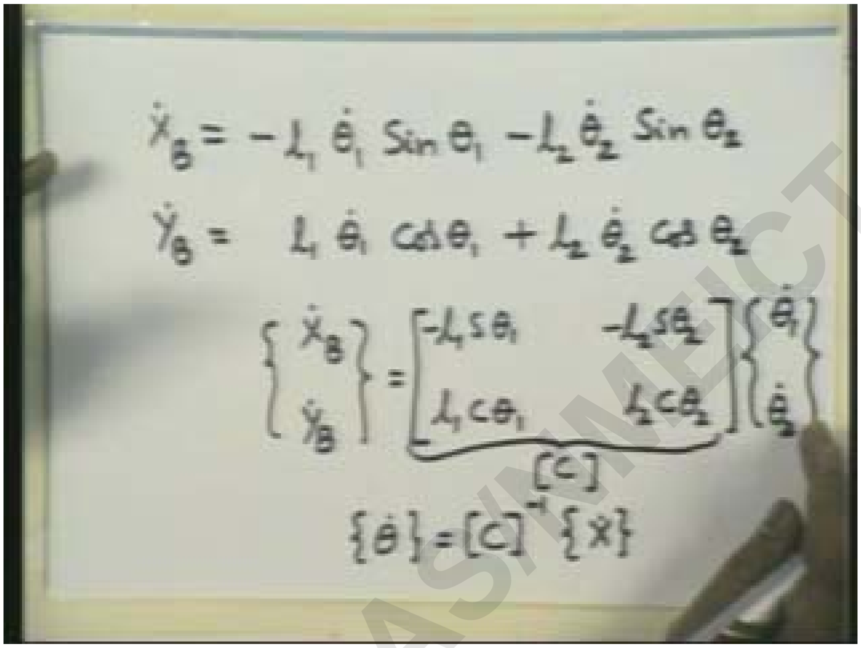
okay so if you look at for example a simple planar two r manipulator let say okay so you may have the x y coordinates global x y coordinates okay we look at a simple two r manipulator okay you want to relate the end effecters motion and the individual joints motion say this is very simple example of a planar manipulator so let me call this point o and this point as A and let this point be B okay so let this link length be L one let this link A B be L two okay and once you design the robotic manipulator the link length L one and L two known to you and this is the two degree of freedom mechanism so each joint motion that is theta one and theta two so joints case will consist of theta one and theta two and the work space coordinates of end effecter will be in terms of x and y global cartesian coordinates of a end effecter team so X B Y B to theta one and theta two this is the kind of relationship that we need to establish and use in our trajectory planning okay this for this simple example is reasonable straight forward we will see how the nature of the relation will be and what is the nature of computation so that perspective of how we plan the motion of end effecter in the actual joint space (Refer Slide time 14:14 min)



so for this particular example that we have taken say you can write the X and Y coordinates which is reasonable straight forward trigonometric relations X B is L one of cos theta one plus L two cos theta two and Y B is L one sine theta one plus L two sine theta two okay now you look at the two simple relations okay if you know how the joints are been moved that means you know theta one and theta two at any instance of time to calculate theta one and theta two been known to calculate X B and Y B is simple linear algebraic equations okay in this particular case it is s two by two set of equations given theta one and theta two L one and L two are known because the robot manipulators mechanism has been designed so it is a simple two by two linear algebraic equation so i would say that the given theta one and theta two to find X B Y B this linear algebraic equation

okay so this is the easier path now look at the other way around that is if i specify that the end effect of the position be a given X B and Y B we need to find what should be the joint motion theta one and theta two at that instant of time such that i get the tip to be a X B and Y B so if you look at that in the reverse so given X B and Y B what will be the theta one and theta two that we will be achieve this position so this is the trigonometric relation therefore this will involve the solution of non linear algebraic equation okay which could have consequent problem of multiple solution you may not have a explicit formula which will compute theta one and theta two in general multiple freedom of mechanism in terms of a specified end effecter position you may have to use that an iterative solvers to come to theta one theta two theta three theta four and so on okay so given X B Y B to find theta one theta two is what is known as non linear algebraic equation slightly more complicated okay now look at we are not satisfied with only the position so look at now the velocity and acceleration phase how this coordinates relationships will get conform so we differentiate this with respect to time and automatically i will get the equation that relate the joint space velocity theta one dot theta two dot with X B dot Y B dot because when this end effecter moves from point A to point B i will require it to move with not only through this point also with certain specific velocity okay within a particular duration of a time

okay i need to bring in that time in to the equation so we need to look at how the velocity can be mapped so this is done simply by the process of differentiate this equation with respect to time so let see what those equation will look like(Ref Slide time 17:40 min)



so X B dot for example will be minus L one theta one dot sine theta one minus L two theta two dot sine theta two Y B dot is L one theta one dot cos theta one plus L two theta two dot cos theta two or in general you want to capture it as a matrix equation X B dot and Y B dot in one side okay i will have minus L one sin theta one i am using the obviated notation s for sine and c for cos so that you get the compact expression minus L two sine theta two L one cos theta one and L two cos theta two with the joint space for net velocity theta one dot theta two dot

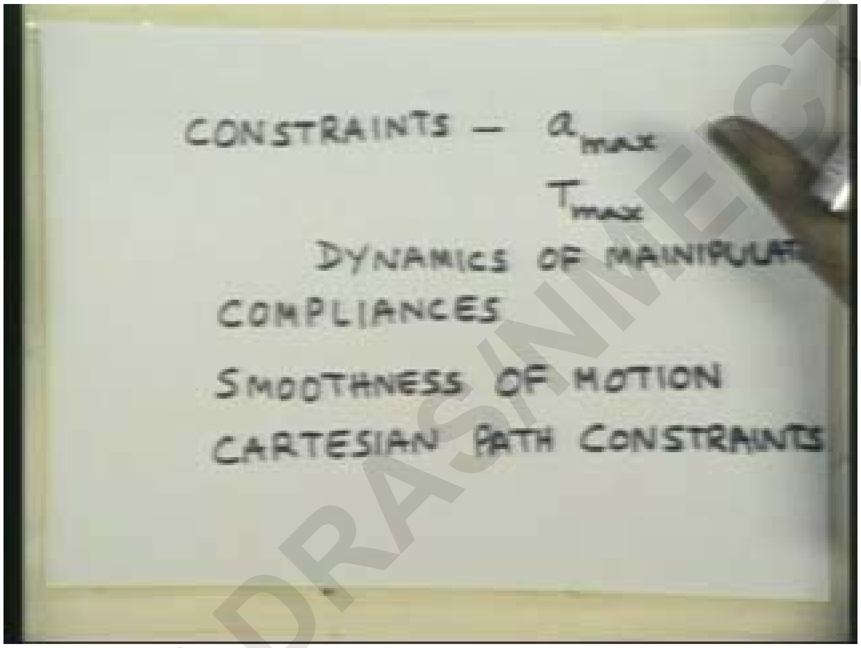
okay here again if you look at the equation the problem statement would be in the following case in the following manner i want them end effecter tip or the robot manipulator joints to move through a particular position with certain velocity so the position information is already known when in talk in terms of velocity so for a given position theta one theta two to being known if you are given theta one dot and theta two dot to find X B dot and Y B dot is the straight forward again linear algebraic equation matrix multiplication will give you the X B dot and Y B dot given X B dot and Y B dot again that is the end effecter velocity through a particular position so once you have specified the position i am assuming that you have already solved the position problem for the joint space velocity position so therefore theta one and theta two are again known to you so given X B dot and Y B dot to be achieved at a particular position determination of theta one and theta two are also is reasonable straight forward you invert this matrix so you if call this as some c okay so theta dot in general is C inverse X dot where i am X dot to indicate X dot to indicate the X and Y components of the velocity of the end effecter tip and theta dot to indicate the all joint space velocity theta one dot theta two dot and so on now this matrix c is typically of this state it is consumable whenever think of the inverse of the matrix it is consumable that inverse may not be exist so you could get into the trouble that all that it means is that the data that has been given in terms of a end effectors desired velocity at that position is not achievable because the particular configuration of the mechanism may be that in a singular configuration so you cannot achieve any arbitrary prescribed velocities in the particular position for the end effect or there is no known solution for the theta dot in terms of specified X dot because the inverse it doesnt exist so it means it is in a similar position

for example okay so such problems could exist but otherwise it is a fairly straight forward linear algebraic equation in the similar manner you can differentiate this equation for the you will be able to relate the acceleration of the end effecter tips that you want through the acceleration in terms of theta one theta two kind of joints variables so the theta one double dot theta two double dot so the acceleration problem would be that at given position and velocity and you want to achieve certain acceleration therefore the position and the velocity in the joint space as well as the cartesian space of the end effecter tip are assume to be known and you are try to determine the joint space acceleration or the end effecter tip acceleration okay so that problem can also be shown to be reasonable straight forward based on further differentiation of the equation okay so what we are really trying to say at this stage is therefore that even though we have given the example of simple two r manipulator for given any robotic manipulator once you know the kinematics configuration once you know the linked length and the types of joins let it be prismatic joint or revolute joint or what ever once you know those you can relate the joint space coordinates generalized coordinates in joint space to the end effecter cartesian motion

so this background being there we can think in terms of planning the end effecter motion in terms of a joint space motions okay that is what we have to we can summaries at this stage yes even though i have such an required end effecter positions velocities that i want to achieve this can be done through a controlled coordinated motion of the individual joints and i can start planning the trajectory in that joint space okay fare enough that when look at joint space trajectory planning that i dont now look at the end effecter but if i look at the joint space trajectory planning in terms of deta one dot deta one deta two deta two dot and so on therefore with respect to time how i get these positions and velocities in terms of the joints coordinates you could think in terms of popular issues that come off before we go ahead of actually doing the planning and so on let look at for example when you focus your attention primarily on the joint space even though the deta one and deta two exactra will vary in particular manner with respect to time say

for example linearly with respect to time it is not necessary that end effecter move through a straight line in the cartesian space so without of the non linear confirmation relation trigonometric relation that connect the joint space coordinate with the end effecter coordinates so we need to the vary of possible interferences obstacles collusion to the obstacles that might happen among the links themselves or the links can end effecter with the obstacles in the environment we need to avoid those okay so this is one issue that we need to keep in mind it is also possible for example that the if you look at the joints if the activators of finite capabilities even though we are now talking in term of kinematics consideration only planning the geometry of motion in a real physical system

you have a activators at each of the joints at certain finite capability so therefore the maximum accelerations that you can achieve for a joint may be specified okay so we will talk in terms of certain constrains coming from the joints activators and other considerations it will affect our planning so look at the for example what we call as the(Refer Slide time 25:04 min)



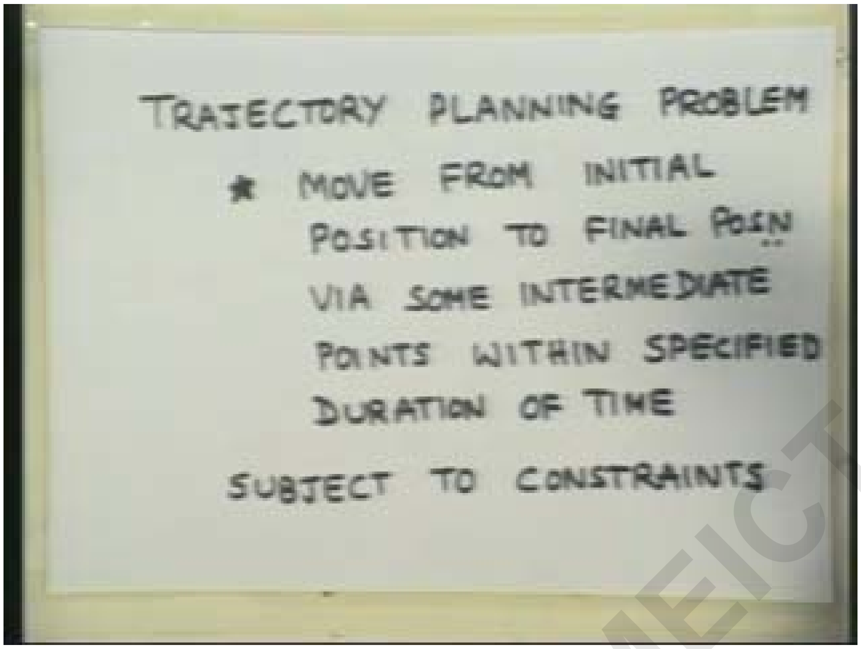
constraints joint constraints so maximum accelerations or the maximum torque that the activator can exact T max for example and so on suppose okay so these constraints come from the dynamics of a manipulator which in real world operating in real conditions okay real joints real activators so therefore certain final capabilities and so you will have certain constrains coming out of this okay this is something we need to keep in mind when we plane our trajectory system another constraint that could come for example from the same line of argument is that the kinematics relation i have derive or i have return on just now or resuming that the links are rigid okay L one and L two are fixed parameter that are known once the two r manipulator was designed and in the motion of the manipulator in its workspace the links are assumed to be rigid but in actual practice when you are talking in terms of very light weight links for example for a manipulator used in a space application with a very long booms as a link length with know extending with the couple of meters or more so you are talking about in terms of long links

okay moving through the workspace at finite acceleration and deceleration so inertia force is to set in vibration in the system the flexibility at the joints in the links themselves okay put the various compliances could initiates vibration in the system so the end effecter tip may not be at the position at you have determine through kinematic relationships based on rigid body rigid length flexibility in the compliances and the joints and the links might affect your calculations okay that is the another effect of the dynamic of the manipulator apart from the maximum capability of the activator itself so compliances will be the another parameter that we need to look at iam trying to highlight you the various complexity involve in the trajectory planning so that we will get a total perspective before we jump into any particular planning scheme so that we get the total perspective of the problem of trajectory planning

okay that is our aim at this stage you could have constrain on the joint motion from the maximum accelerations or from the torque that can be existed or from the compliances therefore flexibility in the vibrations and so on in any case any non smooth motion even if the links are not complaint any non smooth jerky rough motion is undesirable because it could setup vibration it could lead to pick wear and tear of various mechanism elements so you want a certain type of constrain to be place on the smoothness of motion okay so we may have certain smoothness concern so you may want for example velocity and acceleration to be continues

okay that may be your specification okay so smoothness of motion also becomes particular you know desired objectives like this you have a list down different constrain we have already looked at the cartesian path constrains to avoid obstacles okay if you look at the overall problem therefore okay of what comes under trajectory planning if you are trying to achieves say from a initial position to a final position that is specified in say an optimal minimal time projector if you want to plane this could become therefore a complex fairly formidable problem atomization problem in this sense of you have several constrain one set of constrain could be in terms of the cartesian space coordinates because you know the obstacle position location in the three D space so you could have constrains on the motion coming from the cartesian space coordinates you could have constrains on the individual joins capabilities and the smoothness of the motion constrains and so on specified in terms of a joint variables okay so you have mixed type of constrains and you are governing equations and so on supports so optimization a formal optimization problem for determining a optimal trajectory is not a trivial problem

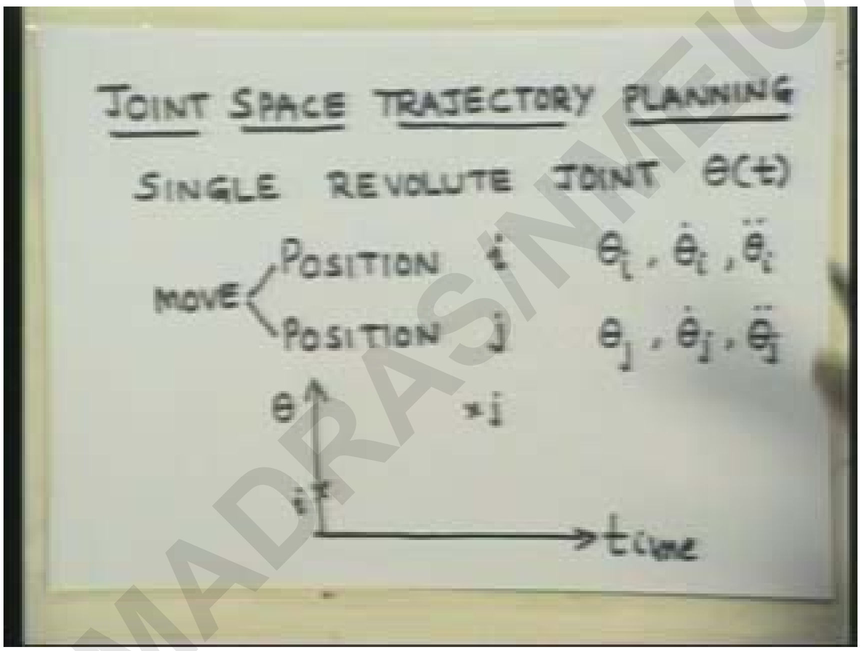
you have similar and at the same time somewhat different type of problem that come up when we talk in term of not fixed stationary robotic manipulator but say example a mobile robot okay like a agv moving around on a shaft floor you may expect it to move around on the shaft floor dynamically avoiding obstacles which could be also moving and not stationary obstacles alone so it has to be dynamically do the path planning in certain minimal time or the least distance from point A to point B and so on support so that the nature of the problem is even further accentuated there in terms of mobile robot application so we will try to summaries and look at the what actually the trajectory planning problem therefore
(Refer Slide time 31:13 min)



if i specify that so trajectory planning problem therefore if you look at that i could state in sense of move from move from initial position to final position via some intermediate point because i am a specify certain intermediate point as the user via some intermediate point and when i keep using the word points always remember that it always implies the position orientation velocity acceleration whatever could be the set of motion variable that are associated with the motion of any typical object so in three D space so it could ask this end effecter also move from initial position to a final position via some intermediate points within a specified duration of time as you want control that speed and the acceleration that are achieve

so within specified duration of time okay subject to some constrain like we just now we discussed okay subject to constrain and the nature of a constrain as we have discussed could be based on the individual joints motions in terms of the capability of the activators and in terms of the smoothness of the motion that you want to be achieve okay depending on the task that you are doing and depending on the manipulator dynamic itself and obstacle avoiding this type of constrain which are in the cartesian space so subject to these various type of constraints we want to able to achieve this kind of motion

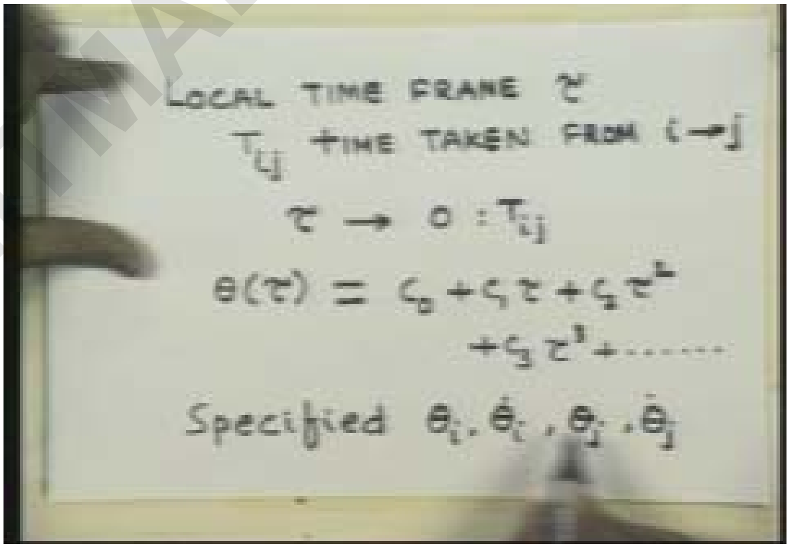
okay this is the overall trajectory planning kind of a problem okay lets look at now while we talk about this overall trajectory planning problem for a robot lets look at a specific individual joints how i can move it from one position to another position okay so that we will do before we look at that lets also remember another issue in this that i am try to move it from one position to another position final position through certain point but this is all a planned trajectory okay a planned set of motion but the real motion is generated in real world in real time okay this is all at the planning stage which is half line essentially okay with the focus of our discussion this is the planning problem offline okay not essentially the dynamic real time path planning type of problem that is further more complicated so we are focusing on our discussion on offline trajectory planning essentially so while we do some planning of the trajectory and motion of that need to get with respect to the time real generation of the motion take place in real world when the robot manipulator operate us so closed loop feedback and control system in three D space and real constraint environment okay so due to the various aspect of the manipulator dynamic effects and redact with the environment effect and point support your planned motion may not be achieved and that way you have various types of sensors that measure actually the motion that is achieve and you have the closely feedback control system that try to ensure that the planned motion is achieved as closely as possible so various types of controls algorithm which will enable you to achieve this planned trajectory will be dealt with separately okay which are typically implemented both at the higher level and at the lower individual joint level various types of things are there those control algorithm will be discussed separately in another set of and we are focused primarily on the offline planning of our trajectory system (Refer Slide time 36:39 min)



let look at for example a simple single individual joint is to be move from one position to another position let look at the some type of the simple problem to begin with so begin with our discussion overall trajectory planning problem this what we have just now discussed we like to do it in the what is known as the joint space planning joint space trajectory planning just look at a single join first then we will worry about a manipulator with several joints so single joins i would say single revolute joint to be more specific but our discussion tends to any type of joint so single revolute joint okay so whose motion is say deta as a function of time okay you want to move it from one position to another position that means so initial position let us say that from position i i did not say the initial or final position i will just consider that the position you want to move it to some position i to position j you want to be move so move from position i to position j that means specified deta i deta i dot deta i double dot in general acceleration support to specify to position deta j certain velocity deta j dot and certain acceleration deta j double dot okay in between two points if you want to move from position i to position j and you want to plane a time and deta so you have certain position here okay i and you have certain position j these could be the initial and final position or these could be any two intermediate position or via point okay

so we take up general two position i and j if you have prescribed deta i deta i dot deta i double dot here at this point and deta j deta j dot deta j double dot what is the smooth trajectory between i and j that i need to use how do i get that kind of trajectory that is the general question now it may happen in particular instances that is these are initial and final position you may say that you are starting from rest so deta i dot deta i double dot may be zero you are reaching placing the object which you have picked up from i at the final position j and also you are reaching with that near zero or zero velocity therefore deta j dot deta j double dot also could be zero you may specify or okay final position so this could be of intermediate positions or via point other side so therefore all this parameter could be non zero okay

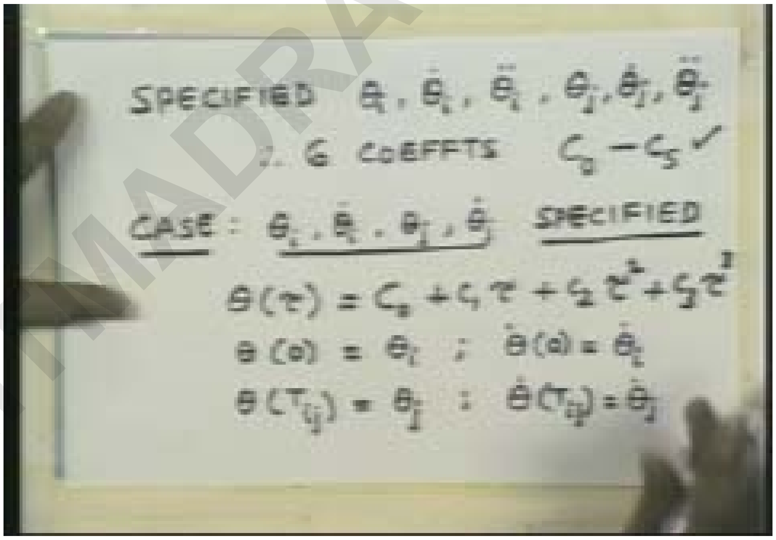
if you able to analyze this problem then we will see that the overall motion of the individual joints creating the final end effecter motion is a case of fitting a series of such point i j k l m n so on so and each set of two points you can actually or a set of points the motion between them can be planned through a particular smooth trajectory that we generate using this type of understanding and you can use several such segments of motion to get the total motion from the initial configuration to the final configuration okay that is the approach we are going to take i look at how i will achieve a particular type of motion between two points i and j in a particular desired motion profile and then see how i can use it for moving the activators from initial position to the final configuration through a set of intermediate position or whatever is the specified so lets look at the particular problem it is easy to see that we are trying to actually find out the motion of the individual joint deta with respect to time so i define first for the sake of convenient of the calculation (Refer Slide time 41:24 min)



on that i define a local time frame when i say local time frame it is local in the sense that it is for the duration of the motion between the two point i and j so tove varies if Tij let

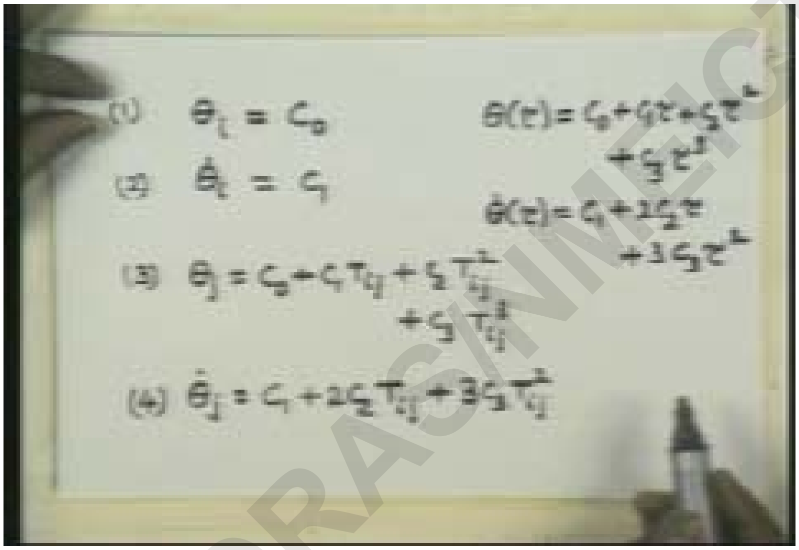
Tij be the time taken time taken from i to j okay so therefore my local time frame that defining tove varies from zero at the beginning of the motion that is at from position i to Tij okay between any two points so my local time frame that i am going to use is tove which varies from zero to the time period between the time duration between any two point i and j given by Tij

so therefore the trajectory i am trying to get would be a trajectory in terms of deta of tove what could be the trajectory that i would get okay i need to plan for this okay we could thing in terms of a polynomial variation of deta with respect to time within this i j and the degree of the polynomial could be determined based on the number of constrains that you are facing because using this constrain you are going to actually determine the coefficient in the linear polynomial that you are going to use so suppose you say that the initial position and initial velocity position at i velocity at i position at j and velocity at j are describe okay so in that case you could have C zero plus C one tove plus C two tove squared plus C three tove cube okay in general we are going to have actually a series of such terms we are going to use a linear polynomial we are going to use a polynomial conflict and the degree of the polynomial will be determine based on the number of coefficient you can determine so if you have six constrain then you can determine six coefficient and correspondingly you can pick an profit of degree polynomial supposing you have the constrain as specified deta i deta i dot deta j deta j dot that means four coefficient can be determined because four constrain are specified and so you can determine c zero c one c two c three so you can determine or you can do a cubic polynomial conflict for the motion between i and j (Refer Slide time 44:36 min)



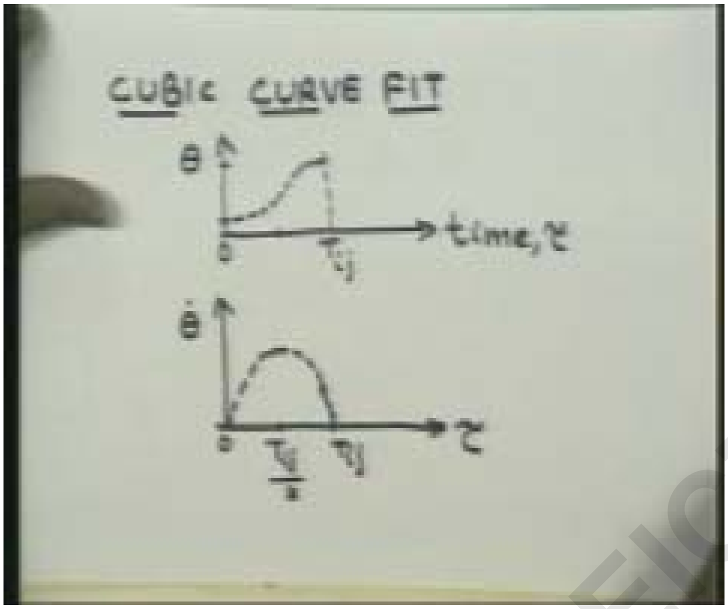
okay if you have also prescribed accelerations that means in the general case if you have specified deta i deta i dot deta i double dot deta j deta j dot deta j double dot
if you have the positions as well as the velocity as well as the activation specified then the number of constrain are six so therefore six coefficients C zero C one C three up to C five can be determined okay you can pick a appropriate degree polynomial okay C five a tove power five go up to the fifth degree polynomial so if you have only position velocity you can go up to a only cubic polynomial and so on so okay now lets look at the simpler

case where only initial to the i and j position and velocity are prescribed and acceleration are not usually specifies so a case where deta i deta i dot deta j deta j dot specified okay that means i am talking about deta tove is specifically C zero plus C one tove plus C two tove square plus C three tove cube okay so now remember that the local time frame tove varies from zero at the highest position to the time division between the points Tij at the j th position so that constrain i have on deta and deta dot can be written as deta of zero that is the highest position deta dot of zero is deta i dot deta corresponding to the time duration between the motion for the point Tij as deta j deta dot corresponding to the motion end of the motion is deta dot okay so we have four constrain and the four coefficient C zero C one C two C three can be determined which is readily done (Refer Slide time 47:23 min)

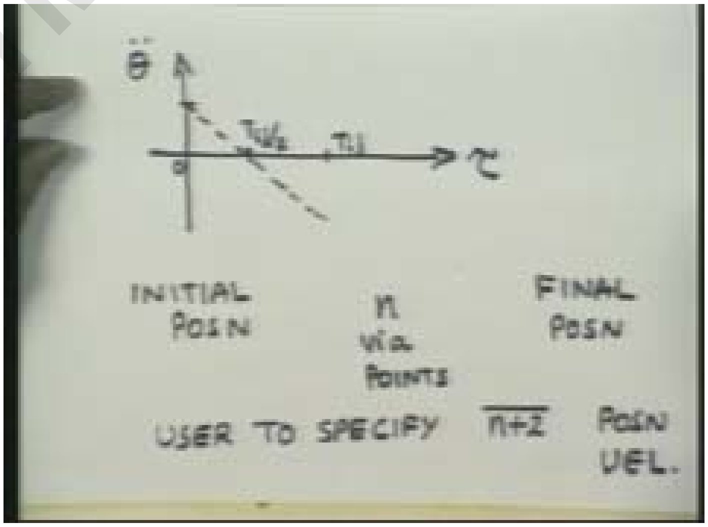


so if you look at the constrain so deta i comes out to be simply C zero deta i dot will come out to be C one because of deta of tove is C zero C one tove plus C two tove square plus C three tove cube

okay deta dot of tove is C one plus two C two tove plus three C three tove square so therefore the tove is equal to zero you have deta is directly C zero and the deta dot is directly to the C one at the other end deta j is the C zero plus C one Tij plus C two Tij square plus C three Tij cube and similarly deta j dot is obtain by substuting by tove os equal to tij in the equation for the velocity here and so deta dot j is C one plus two C two Tij plus three C three Tij square okay i could call this equation one equation two equation three and equation four so four equation determine C zero C one C two C three this can be generalize as i said i mean if you have prescribed acceleration that you can fit higher degree polynomial differentiate it for velocity differentiate it for acceleration and make the profile match the condition prescribed at i and j okay (Refer Slide time 49:26 min)

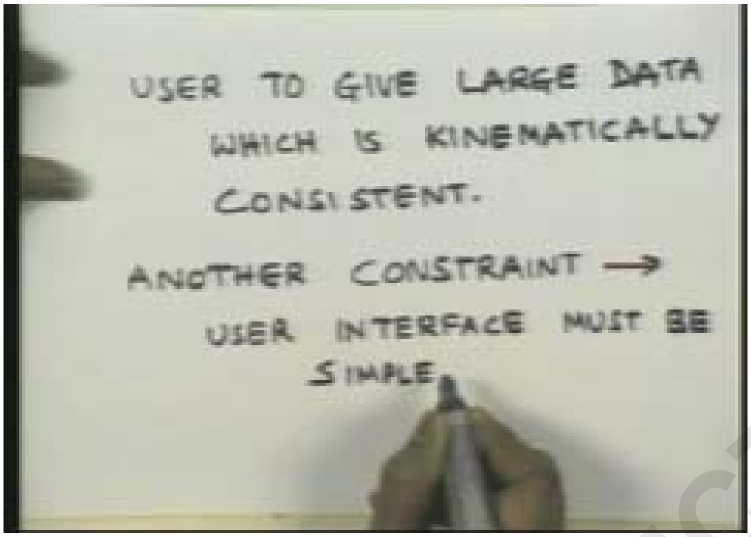


so if you look at the cubic curve fit we have got the cubic curve fit that we just now achieved it is it has simple advantages which the lowest degree polynomial that ensure the continuity of velocity and acceleration because the cubic client will ensure the velocities and accelerations second derivative continuity is directory so it is the lowest degree polynomial that achieve this stage and it is readily computed as we have just now seen so it is one of the common plane interpolation scheme thisis implemented in practice cubic space if you look at the example for this type of a cubic plane strategy they typical position variation with respect to time could be something like this okay this is Tij this is zero time tove in the local coordinates time between deta i to deta j okay and corresponding time your velocities would be something like this is Tij this is Tij upon Q zero you have peak velocity here and you are moving like this okay your velocity profile for this type of cubic polynomial would look like this now if you look at the how the acceleration will be for this type of the cubic plane segments (Refer Slide time 51:19 min)



then the accelerations that is deta double dot will be something like this Tij and the accelerations will move like this okay accelerations to be linear Tij upon two at a half way point cross to zero where the peak velocity is then it will be the deceleration phase half the way you will have this type of deceleration point so given any two position i and j with prescribed velocities you will be able to determine the coefficient C zero Cone C two C three for the cubic plane for which for the individual joint motion in this manner okay once you got the coefficient given any value of Tij and the variable value deta dot deta deta i deta dot i deta j deta j dot you will be able to compute this actually generate the motion through the individual joints okay so this is feasible but look at how it would be implemented in the actual practice if you have a n number of points through which you want the motion to be achieve okay in this type of strategy of doing the curve thing you are requiring that all the positions be specified and the velocities may be in terms of a end effecter motion and you can do the inverse kinematics to do the to calculate through the kinematics relationship the joints space velocities okay

but somebody has to specify by all the velocity at all the points if you have say initial position okay just imagine how this type of strategy will be implemented in actual and then i have a final position where i need to go n points in between okay between so i have totally n plus two positions and n plus two velocities have to be specified by the user okay at each of this position for this strategic work to be implemented in practice then i need to specify if the user is require to specify user to specify n plus two positions and velocity okay in terms of trajectory planning we now come up with another aspect of trajectory planning that whatever strategy you do inside is internal to the manipulator as for as the interface with the user is concern unit is to have a way of specifying it on a simple manner user shouldnt have to be shouldnt have to give huge amount of data okay that is something we need to keep in mind another aspect that would come up when you are asking for such data from the user is that as i have indicated in the kinematics relationship from the velocities in the joints space to the cartesian space the velocity that the user specify at all the positions may not to be achievable okay the user not only has to give large data but also has to give consistence data okay so in this particular strategy of specifying the trajectory planning
(Refer Slide time 55:25 min)



then user need to give to give large data that is one aspect okay n plus two positions he has to give the position and velocity of the information but it has to be also kinematical consistence data which is kinematically consistent okay so in terms of user interface therefore we come up to trajectory planning we look at it in another angle and then we add another constraint so to say which say that the user interface should be simple okay so another constraint therefore from the interface point of view is that user interface must be simple that is we dont have to give complicated expression function of time for the specification of the task which is in world coordinate for him as the user as he should say he should be able to in simple manner specify the task that needs to be done that also closes up to the light that may be many of the intermediate point via point he doesnt really bother that them the end effecter tip exactly pass through those point it could approximately there or even it is exactly passing it through those point he may be really worry about what is the velocity with which the end effecter tip moves through though okay it may be left to the system to calculate what could be an appropriate velocity to move through such a via point so we will see how we can generalize this type of strategy of trajectory planning in the next class for via points where velocity are not really specify so the user simply says go from a initial position to a final position through this via point okay we will see the strategy of trajectory planning for those staircases in next lecture