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ЎЗБЕКИСТОН РЕСПУБЛИКАСИ ОЛИЙ ВА ЎРТА МАХСУС ТАЪЛИМ ВАЗИРЛИГИ

НАМАНГАН ДАВЛАТ УНИВЕРСИТЕТИ ИЛМИЙ АХБОРОТНОМАСИ

НАУЧНЫЙ ВЕСТНИК НАМАНГАНСКОГО ГОСУДАРСТВЕННОГО УНИВЕРСИТЕТА

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OBYEKT BOSHQARUVINING KOORDINATALARI O'ZARO BOG'LIQSIZ BO'LGANDA OPTIMAL O'TISH MASALASI

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Annotatsiya. *Ushbu maqolada obyekt boshqaruvining koordinatalari o'zaro bog'liqsiz bo'lgan holda optimal boshqaruv nazariyasida obyektning tekislikning istalgan nuqtasiga optimal o'tishi masalasi o'rganilgan. Bunda tekislik to'rtta sohaga ajratilib,har bir soha uchun boshqaruv va eng qisqa o'tish vaqti aniqlanadi.*

Kalit so'zlar. *Geometrik chegaralanish, obyekt, trayektoriya, o'lchanuvchi funksiya, tezlik, koordinata, optimal o'tish vaqti.*

THE PROBLEM OF OPTIMAL TRANSITION WHEN THE COORDINATES OF THE OBJECT CONTROL ARE INDEPENDENT EACH OTHER

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Abstract. *This article explores the problem of optimal transition of an object to any point in the plane in the theory of optimal control, where the coordinates of the control of the object are independent of each other. In which the plane is divided into four areas, and the control and transition times are determined for each area.*

Keywords. *Geometric constraint, object, trajectory, measurable function, velocity, coordinate, optimal transition time.*

ЗАДАЧА ОПТИМАЛЬНОГО ПЕРЕХОДА ПРАВЛЕНИЯ КООРДИНАТАМИ ОБЬЕКТОВ НЕ СВЯЗАННЫХ ДРУГ С ДРУГОМ.

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Аннотация: *В этой статье изучается задача оптимального перехода правления координатами обьектов не связанных друг с другом. Здесь пространство делится на четыре обьекта, в которых определяется управление и краткое время перехода.*

Ключевые слова: *геометрические ограничертя обьект, траектория, измеряемая функция, скорость, координаты оптимальное время перехода.*

1. Introduction

Today the theory of optimal control is one of the most widely studied speciality.In this theory, the study and application of problems is important for cases where control parameters are different. [1,2,3,4] Many scholars have solved a number of promlems in this speciality. [5,6,7] This article explores the problem of optimal transition of an object to any point in the plane, where the coordinates of the control of the object are independent of each other. Problems related to this were studied by the L. C. Pontryagin, the E.F. Mishenko ,who took the problem to the pursuit-evasion differential games. [2] They studied the transition of an object to a point in the plane in square Γ and determined that passes at time $[t_1, t_1+\theta]$ by selecting the control $\|\pi z(t)\| \geq \gamma t^k$,where $\theta \leq \min\left\{1, \frac{\gamma}{c_3}\right\}, t \in [0,\theta]$. [2,8] In addition, the motion of an object has been studied in triangles, rectangles and cones.This article is studied in a straight rectangle as opposite to the previous ones. In which the shortest transition time to point P was found using the division of the plane into areas with coordinates independent of each other.[8]

2. Statement of the problem.

Given an object $\mathbf{E}$ moving in space R^2, let its position in plane be $x=(x_1, x_2)$. In this case, we express the coordinates of the equation of motion of the object in the plane as follows

$$\mathbf{E}: \begin{array}{ll} \dot{x}_1 = u_1, & x_1(0) = x_{10}, \\ \dot{x}_2 = u_2, & x_2(0) = x_{20}, \end{array} \qquad (1)$$

where u_1 is the velocity of the first coordinate, u_2 is the velocity of the second coordinate. The points $x_1, x_2, u_1, u_2 \in R^2, n \geq 2$; $x_1(0) = x_{10}$, $x_2(0) = x_{20}$ are the initial condition of the object in terms of coordinates respectively at $t = 0$, where $x_0 \neq y_0$. The control parameter $u = (u_1(t), u_2(t))$ of the object $\mathbf{E}$ is chosen as a measurable function with respect to t and mapping $u(\cdot):[0,+\infty) \to R^2$. In this control problem, the coordinates of the object control are selected as accordingly measurable functions and they satisfy the following geometric constraints (constraints G)

$$|u_1(t)| \leq \alpha \text{, in almost all } t \geq 0, \tag{2}$$

$$|u_2(t)| \leq \beta \text{, in almost all } t \geq 0, \tag{3}$$

where $\alpha, \beta > 0$.

We denote by U_1 and U_2 respectively the set of measured functions $u_1(t)$ and $u_2(t)$ that satisfy the constraints (2) and (3).

Definition 1. The function

$$x_1(t, u_1(\cdot)) = x_{10} + \int_0^t u_1(s)ds,\ t \geq 0, \tag{4}$$

$$x_2(t, u_2(\cdot)) = x_{20} + \int_0^t u_2(s)ds,\ t \geq 0 \tag{5}$$

corresponding to any $(x_{10}, u_1(\cdot)),\ \ u_1(\cdot) \in U_1,$
$(x_{20}, u_2(\cdot)),\ \ u_2(\cdot) \in U_2$

pairs are called object coordinate trajectories.

Definition 2. The motion of an object $\mathbf{E}$ in the plane is called the following equation

$$x(t) = (t, u_1(t), u_2(t)),\ t \geq 0 \tag{6}$$

According to this definition, for different $u_1(\cdot) \in U_1$, $u_2(\cdot) \in U_2$ controls, different trajectories are generated from the initial position $x_0 = (x_{10},\ x_{20})$.

1.1. Problem 1. Find the area of reach of the object at each coordinate in the plane from the given initial position $x_0 = (x_{10},\ x_{20})$.

Lemma 1. If the velocities of an object moving by Equation (1) satisfy the geometric constraint (2), (3) respectively, then the object lies within the following set at each time interval $t \geq 0$

$$R = \{(x_1, x_2) : |x_1 - x_{10}| \leq \alpha t,\ |x_2 - x_{20}| \leq \beta t\} \tag{7}$$

According to Lemma 1 , set (7) represents a right rectangle $ABCD$ whose coordinates are at points $A(x_{10} - \bar{\alpha},\ x_{20} + \bar{\beta})$, $B(x_{10} + \bar{\alpha},\ x_{20} + \bar{\beta})$, $C(x_{10} + \bar{\alpha},\ x_{20} - \bar{\beta})$, $D(x_{10} - \bar{\alpha},\ x_{20} - \bar{\beta})$ in the (x_1, x_2) plane, where $\bar{\alpha}, \bar{\beta} > 0$. $\bar{\alpha} = \alpha t$, $\bar{\beta} = \beta t$.

1.2. Problem 2. Find the optimal control and the shortest transition time from a given $x_0 = (x_{10},\ x_{20})$ initial position to a point $P = (p_1, p_2)$ at the plane.

Let us first consider the problem for the $x_{10}=0$, $x_{20}=0$ case. If we draw straight lines $x_2=\frac{\beta}{\alpha}x_1$ and $x_2=-\frac{\beta}{\alpha}x_1$ from the origin, the plane (x_1,x_2) is divided into the following areas

$$\Pi_1=\left\{(x_1,x_2):x_2>\frac{\beta}{\alpha}x_1,x_2>-\frac{\beta}{\alpha}x_1\right\},$$

$$\Pi_2=\left\{(x_1,x_2):x_2<\frac{\beta}{\alpha}x_1,x_2>-\frac{\beta}{\alpha}x_1\right\},$$

$$\Pi_3=\left\{(x_1,x_2):x_2<\frac{\beta}{\alpha}x_1,x_2<-\frac{\beta}{\alpha}x_1\right\},$$

$$\Pi_4=\left\{(x_1,x_2):x_2>\frac{\beta}{\alpha}x_1,x_2<-\frac{\beta}{\alpha}x_1\right\}.$$

Suppose that $\mathbf{E}$ is the initial position of the object at the beginning of the coordinates.

3. The main results

Lemma 2. For an given point $P=(p_1,p_2)$ and object $\mathbf{E}$ in the plane R^2, the following is appropriate

1) If $P\in\Pi_1$ ($P\in\Pi_3$), then the object $\mathbf{E}$ passes through the control $u_1=\left(\beta\frac{p_1}{p_2},\beta\right)$ $\left(u_3=\left(-\beta\frac{p_1}{p_2},-\beta\right)\right)$ to the point P at time $T_1=T_3=\left|\frac{p_2}{\beta}\right|$,

2) If $P\in\Pi_2$ ($P\in\Pi_4$), then the object $\mathbf{E}$ passes through the control $u_2=\left(\alpha,\alpha\frac{p_2}{p_1}\right)$ $\left(u_4=\left(-\alpha,-\alpha\frac{p_2}{p_1}\right)\right)$ to the point P at time $T_2=T_4=\left|\frac{p_1}{\alpha}\right|$,

3) If $P\in\bar{\Pi}_1$ ($P\in\bar{\Pi}_2$), then the object $\mathbf{E}$ passes through the control $\bar{u}_1=(\alpha,\beta)$ or $\bar{u}_1=(-\alpha,-\beta)$ $\left(\bar{u}_2=(-\alpha,\beta)\text{ or }\bar{u}_2=(\alpha,-\beta)\right)$ to the point P at time $\bar{T}=\left|\frac{p_2}{\beta}\right|=\left|\frac{p_1}{\alpha}\right|$,

where $\bar{\Pi}_1=\left\{(x_1,x_2):x_2=\frac{\beta}{\alpha}x_1\right\},\bar{\Pi}_2=\left\{(x_1,x_2):x_2=-\frac{\beta}{\alpha}x_1\right\}$

Proof.

1. Suppose $P=(p_1,p_2)\in\Pi_1$. Let's draw an OP segment, K denote the point of intersection of the OP segment with the AB segment. Its coordinates are $K(\tilde{\alpha}_1,\tilde{\beta})$,where $p_1,p_2,\tilde{\alpha}_1,\tilde{\alpha},\tilde{\beta}>0;\ \tilde{\alpha}_1=\alpha_1\cdot T_1,\tilde{\alpha}=\alpha\cdot T_1,\tilde{\beta}=\beta\cdot T_1,OM=(\tilde{\alpha}_1,0)$.From the similarity of triangles ΔOKM and ΔOPP_1

$$\frac{OM}{OP_1}=\frac{MK}{PP_1}\Rightarrow\frac{\alpha_1}{p_1}=\frac{\beta}{p_2}\Rightarrow\alpha_1=\beta\cdot\frac{p_1}{p_2}$$

where $\tilde{\alpha}_1<\tilde{\alpha}\Rightarrow\alpha_1<\alpha$. From which we derive the following for the above equations

$$\frac{\beta}{p_2}=\frac{\alpha_1}{p_1}<\frac{\alpha}{p_1}\Rightarrow\frac{\alpha}{p_1}>\frac{\beta}{p_2} \quad (8)$$

If in this case the object $\mathbf{E}$ is moving at the velocity $\overrightarrow{OK}(\alpha_1,\beta)$, we choose the control $u_1=(u_{11},u_{12})$ in the

$$u_1=\overrightarrow{OK}=\left(\beta\cdot\frac{p_1}{p_2},\beta\right) \quad (9)$$

view, which moves the object from point O to point P.

Let (9) check that control satisfies the constraint (2)

$$|u_{11}|=\left|\beta\cdot\frac{p_1}{p_2}\right|=\left|\frac{\beta}{p_2}\right|\cdot|p_1|<\left|\frac{\alpha}{p_1}\right|\cdot|p_1|=\alpha,\ |u_{12}|=|\beta|=\beta$$

We now determine the time at which object $\mathbf{E}$ falls to point P using control (9)

$$T_1=\frac{|OP|}{|\overrightarrow{OK}|}=\frac{\sqrt{p_1^2+p_2^2}}{\sqrt{\alpha_1^2+\beta^2}}=\frac{\sqrt{p_1^2+p_2^2}}{\sqrt{\frac{p_1^2}{p_2^2}\cdot\beta^2+\beta^2}}=\frac{p_2}{\beta} \quad (10)$$

As well as according to relation (8), $T_1=\frac{p_2}{\beta}>\frac{p_1}{\alpha}$ is appropriate. Thus the time taken for the object $\mathbf{E}$ to fall to point P is equal to the value of $T_1=\frac{p_2}{\beta}$.

We now show that the object $\mathbf{E}$ falls to point at exactly time T_1 using control (9).

$$u_1\cdot T_1=\left(\beta\cdot\frac{p_1}{p_2},\beta\right)\cdot T_1=\left(\beta\cdot\frac{p_1}{p_2},\beta\right)\cdot\frac{p_2}{\beta}=(p_1,p_2).$$

Since the areas Π_1 and Π_2 are symmetrical to each other, if $P\in\Pi_3$, then object $\mathbf{E}$ falls to the point P at time $T_1=T_3=\left|\frac{p_2}{\beta}\right|$ through control $u_3=\left(-\beta\frac{p_1}{p_2},-\beta\right)$. This can also be shown as above.

2. Suppose $P=(p_1,p_2)\in\Pi_2$. In this case also let us draw the OP segment, K denote the point of intersection of the OP segment with the AB segment. Its coordinates are $K(\tilde{\alpha},\tilde{\beta}_1)$, where $p_1,p_2,\tilde{\beta}_1,\tilde{\alpha},\tilde{\beta}>0;\ \tilde{\beta}_1=\beta_1\cdot T_2,\tilde{\alpha}=\alpha\cdot T_2,\tilde{\beta}=\beta\cdot T_2,OM=(0,\tilde{\beta}_1)$. From the similarity of triangles ΔOKM and ΔOPP_1

$$\frac{OM}{OP_1}=\frac{MK}{PP_1}\Rightarrow\frac{\alpha}{p_1}=\frac{\beta_1}{p_2}\Rightarrow\beta_1=\alpha\cdot\frac{p_2}{p_1}$$

where $\tilde{\beta}_1<\tilde{\beta}\Rightarrow\beta_1<\beta$. From which we derive the following for the above equations

$$\frac{\alpha}{p_1}=\frac{\beta_1}{p_2}<\frac{\beta}{p_2} \Rightarrow \frac{\alpha}{p_1}<\frac{\beta}{p_2} \qquad (11)$$

If in this case the object $\mathbf{E}$ is moving at the velocity $\overrightarrow{OK}(\alpha,\beta_1)$, we choose the control $u_2=(u_{21},u_{22})$ in the

$$u_2=\overrightarrow{OK}=\left(\alpha,\alpha\cdot\frac{p_2}{p_1}\right) \qquad (12)$$

view, which moves the object from point O to point P.
Let (12) check that control satisfies the constraint (3)

$$|u_{21}|=|\alpha|=\alpha,\ |u_{22}|=\left|\alpha\cdot\frac{p_2}{p_1}\right|=\left|\frac{\alpha}{p_1}\right|\cdot|p_2|<\left|\frac{\beta}{p_2}\right|\cdot|p_2|=\beta$$

We now determine the time at which object $\mathbf{E}$ falls to point P using control (12)

$$T_2=\frac{|OP|}{|\overrightarrow{OK}|}=\frac{\sqrt{p_1^2+p_2^2}}{\sqrt{\alpha^2+\beta_1^2}}=\frac{\sqrt{p_1^2+p_2^2}}{\sqrt{\alpha^2+\frac{p_2^2}{p_1^2}\cdot\alpha^2}}=\frac{p_1}{\alpha} \qquad (13)$$

As well as according to relation (11), $T_2=\frac{p_1}{\alpha}>\frac{p_2}{\beta}$ is appropriate.Thus the time taken for the object $\mathbf{E}$ to fall to point P is equal to the value of $T_2=\frac{p_1}{\alpha}$.

We now show that the object $\mathbf{E}$ falls to point at exactly time T_2 using control (12).

$$u_2\cdot T_2=\left(\alpha,\alpha\cdot\frac{p_2}{p_1}\right)\cdot T_2=\left(\alpha,\alpha\cdot\frac{p_2}{p_1}\right)\cdot\frac{p_1}{\alpha}=(p_1,p_2).$$

Since the areas Π_2 and Π_4 are symmetrical to each other, if $P\in\Pi_4$, then object $\mathbf{E}$ falls to the point P at time $T_2=T_4=\left|\frac{p_1}{\alpha}\right|$ through control $u_4=\left(-\alpha,-\alpha\frac{p_2}{p_1}\right)$. This can also be shown as above.

3. Suppose that the point P lies on the line Π_1 in the first quarter of the coordinate plane (x_1,x_2). Where the coordinates of point K overlap with point B and $K(\tilde{\alpha},\tilde{\beta})$, where $p_1,p_2,\tilde{\alpha},\tilde{\beta}>0,\ \tilde{\alpha}=\alpha\cdot\bar{T},\tilde{\beta}=\beta\cdot\bar{T}$. In this case we select the control for object $\mathbf{E}$ as follows

$$\bar{u}_1=\overrightarrow{OK}=(\alpha,\beta) \qquad (14)$$

$p_2=\frac{\beta}{\alpha}p_1$ according to $x_2=\frac{\beta}{\alpha}x_1$. Using control (14), the transition time of object $\mathbf{E}$ to point P is as follows

$$\bar{T}_1 = \frac{\sqrt{p_1^2 + p_2^2}}{\sqrt{\alpha^2 + \beta^2}} = \frac{\sqrt{p_1^2 + \left(\frac{\beta}{\alpha} p_1\right)^2}}{\sqrt{\alpha^2 + \beta^2}} = \frac{|p_1|}{\alpha} \qquad (15)$$

If $p_1 = \frac{\alpha}{\beta} p_2$ on the other hand $\bar{T}_1 = \frac{|p_2|}{\beta}$. From this we obtain the result $\frac{|p_2|}{\beta} = \frac{|p_1|}{\alpha}$. If the point P lies on the line Π_1 in the third quarter of the coordinate plane (x_1, x_2), then $\bar{u}_1 = (-\alpha, -\beta), \bar{T}_1 = \left|\frac{p_2}{\beta}\right|$ for the object $\mathbf{E}$

Since the areas $\bar{\Pi}_1$ and $\bar{\Pi}_2$ are symmetrical to each other, if the point P lies on the line $\bar{\Pi}_2$ in the second (fourth) quarter of the coordinate plane (x_1, x_2), then object $\mathbf{E}$ falls to the point P at time $\bar{T}_2 = \left|\frac{p_1}{\alpha}\right| = \left|\frac{p_2}{\beta}\right|$ through control $\bar{u}_2 = (-\alpha, \beta)$ $(\bar{u}_2 = (\alpha, -\beta))$.From this

$\bar{T}_1 = \bar{T}_2 \Rightarrow \mathrm{T} = \left|\frac{p_2}{\beta}\right| = \left|\frac{p_1}{\alpha}\right|$.

Lemma 2 proved.

Using Lemma 1 and Lemma 2, the following theorem can be proved.

Theorem 1. The object $\mathbf{E}$ passes to the any point $\boldsymbol{P} \in \boldsymbol{R}^2$, $P = (p_1, p_2)$ from the origin at the shortest time $T = \max\left\{\frac{|p_1|}{\alpha}, \frac{|p_2|}{\beta}\right\}$ through the following control

$$u^* = \left\{\min\left\{\beta\frac{p_1}{p_2}, \alpha\right\}, \min\left\{\alpha\frac{p_2}{p_1}, \beta\right\}\right\}.$$

If $x_0 \neq 0$, the following theorem is valid.

Theorem 2. The shortest transition time of an object $\mathbf{E}$ to any point $\boldsymbol{P} \in \boldsymbol{R}^2$, $P = (p_1, p_2)$ of the plane through the control $u^* = \left\{\min\left\{\beta\frac{|p_1 - x_{10}|}{|p_2 - x_{20}|}, \alpha\right\}, \min\left\{\alpha\frac{|p_2 - x_{20}|}{|p_1 - x_{10}|}, \beta\right\}\right\}$ is as following

$$T = \max\left\{\frac{|p_1 - x_{10}|}{\alpha}, \frac{|p_2 - x_{20}|}{\beta}\right\}.$$

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НЕЛОКАЛЬНАЯ КРАЕВАЯ ЗАДАЧА ДЛЯ НЕЛИНЕЙНОГО УРАВНЕНИЯ НЕЧЕТНОГО ПОРЯДКА С КРАТНЫМИ ХАРАКТЕРИСТИКАМИ

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Аннотация: *В статье доказано существовании единственное решение нелокальной краевой задачи для нелинейного уравнения с кратными характеристиками нечетного порядка*

Ключевые слова: *с кратными характеристиками, нечётного порядка, единственность решения, существование решение, условия Липшица.*

КАРРАЛИ ХАРАКТЕРИСТИКАЛИ ТОҚ ТАРТИБДАГИ ЧИЗИҚЛИ БЎЛМАГАН ТЕНГЛАМА УЧУН НОЛОКАЛ МАСАЛА

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Аннотация: *Мақолада характеристикаси каррали бўлган тоқ тартибдаги чизиқли бўлмаган тенглама учун нолокал чегаравий шартли масаланинг ягона ечимининг мавжудлиги исботланган.*

Калит сўзлар: *Каррали характеристика, тоқ тартибли, ечимнинг ягоналиги, ечимнинг мавжудлиги, Липшиц шарти.*

NONLOCAL BOUNDARY VALUE PROBLEM FOR ODD ORDER NONLINEAR EQUATION WITH MULTIPLE CHARACTERISTICS

Artiqov Maxamadi
Termez State University
PhD in Physics-Mathematical Sciences

МУНДАРИЖА

01.00.00 ФИЗИКА-МАТЕМАТИКА ФАНЛАРИ
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