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CHIZIQLI BO‘LMAGAN AYIRMALI TENGLAMALAR SISTEMASINING YECHIMLARINING MAVJUDLIGI VA YAGONALIGI HAQIDA

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Anotatsiya: Ushbu maqolaning maqsadi ko‘p o‘zgaruvchan usullar bilan birinchi tartibli qisman hosilalarda chiziqli bo‘lmagan differensial tenglamalar tizimini qo‘shimcha argumentlar bilan yechish, ular yordamida ko‘rib chiqilgan tenglamalar tizimini integral tenglamalar tizimiga keltirishdir. Chiziqli bo‘lmagan qisman differensial tenglamalar tizimini xarakteristikalar usuli bilan hamda noma’lum funksiyalarning superpozitsiyasi doimo mavjud bo‘lgan integral tenglamalarning chiziqli bo‘lmagan tizimini o‘rganish. Cheklash usuli. Usulning mohiyati shundan iboratki, differensial tenglamalar tizimini yechish jarayonida bitta differensial tenglamaga keltiriladi. Ushbu tadqiqotdan matematik-fizika tenglamalari fanini o‘rganish davomida bitiruvchi kurs talabalari va magistrantlar uchun maxsus kurslar o‘qitishda hamda ushbu sohada ilmiy tadqiqot jarayonida foydalanish mumkin.

Nochiziqli tenglamalar sistemasini yechishda qo‘llanilgan usullarni o‘rganishda tadbiq etiladi. Nochiziqli to‘g‘ridan to‘g‘ri boshlang‘ich masalalarni sonli yechishda ham qo‘llaniladi. bir vaqtning o‘zida qo‘zg‘almas to‘rlarni qo‘llaydigan usullardan (sonli farqlash amalga oshirilmaydi) va xarakteristikalar usuli kabi usullardan (hisoblash siniq chiziqlar bo‘ylab emas, balki to‘g‘ri chiziqlar bo‘ylab amalga oshiriladi) afzalliklarga ega. Bundan tashqari, bu usul, i.u. uchun natijalardan foydalanganligi sababli, kafolatlangan natijalarni olish uchun qulayroqdir.

Kalit so‘zlar: Chiziqli bo‘lmagan tenglamalar sistemasi, qisman differensial tenglama, tenglamalar tizimi, boshlang‘ich shartlar, qo‘shimcha argument, kechiktirilgan turdagi operator.

О СУЩЕСТВОВАНИИ И ЕДИНСТВЕННОСТИ РЕШЕНИЙ СИСТЕМЫ НЕЛИНЕЙНЫХ ДИФФЕРЕНЦИАЛЬНЫХ УРАВНЕНИЙ

Аннотация: Целью данной статьи является решение системы нелинейных дифференциальных уравнений в частных производных первого порядка методами многих переменных с дополнительными аргументами, приведение рассматриваемой системы уравнений к системе интегральных уравнений. Изучить систему нелинейных уравнений в частных производных методом характеристик и нелинейную систему интегральных уравнений, в которой всегда имеется суперпозиция неизвестных функций. Метод ограничения. Сущность метода состоит в том, что в процессе решения системы дифференциальных уравнений она сводится к одному дифференциальному уравнению. Данная диссертация может быть использована при преподавании спецкурсов для аспирантов и магистрантов при изучении математико-физических уравнений, а также в процессе научных исследований в этой области.

Он применяется при исследовании методов, используемых при решении системы нелинейных уравнений. Нелинейная линейная регрессия также используется для численного решения элементарных задач. одновременно имеет преимущества перед методами, использующими фиксированные сетки (не проводится численное дифференцирование) и

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такими методами, как метод характеристик (расчет ведется по прямым, а не по ломаным линиям). Кроме того, этот метод, т.е. поскольку он использует результаты для , удобнее получать гарантированные результаты.

Ключевые слова: Система нелинейных уравнений, уравнение в частных производных, система уравнений, начальные условия, дополнительный аргумент, оператор с запаздыванием.

ON THE EXISTENCE AND UNIQUENESS OF SOLUTIONS TO A SYSTEM OF NONLINEAR DIFFERENTIAL EQUATIONS

Annatation: The purpose of this article is to solve a system of nonlinear partial differential equations of the first order with additional arguments using multivariable methods, and to reduce the considered system of equations to a system of integral equations. To study a system of nonlinear partial differential equations by the method of characteristics and a nonlinear system of integral equations in which the superposition of unknown functions is always present. Limitation method. The essence of the method is that in the process of solving a system of differential equations, the system is reduced to a single differential equation. This dissertation can be used in teaching special courses for graduate students and undergraduates in the study of mathematical-physical equations, as well as in the process of scientific research in this area.

It is applied in the study of methods used in solving systems of nonlinear equations. Nonlinear direct methods are also used in the numerical solution of elementary problems. It has advantages over methods using fixed meshes (numerical differentiation is not performed) and over methods such as the method of characteristics (the calculation is performed along straight lines, not along broken lines). In addition, this method is more convenient for obtaining guaranteed results, since it uses the results for i.u.

Key words: Nonlinear system of equations, partial differential equation, system of equations, initial conditions, additional argument, delayed type operator.

KIRISH. Hozirgi vaqtda chiziqli bo‘lmagan qisman differensial tenglamalar tizimlari uchun qo‘shimcha argument usuli ishlab chiqilmoqda.

M.I. Imanaliev o‘zining “Qisman hosilali nochiziqli integrodifferensial tenglamalar” asarida “shartlanuvchi xaritalar” tamoyili asosida ishlab chiqilgan maqoladan foydalangan holda, qisman hosilalardagi turli nochiziqli differensial tenglamalar o‘qdagi dastlabki shartlar bilan integral tenglamalarga (ya’ni) keltirildi va ba’zi sohalarda mavjudlik va yagonalik uchun yetarli shartlar topildi.

Ushbu usulning aksiomatik asoslari maqolada ochib berilgan. Bu yerda ham tegishli yangi tushuncha va ta’riflar kiritilgan. Ko‘rsatilishicha, maqolada asosiysi shundaki, qisman differensial operatorlar ma’lum ma’noda integral operatorlar bilan almashtiriladi, bu esa qisqacha "kvazi-kommutativlik" deb ataladi.

Nochiziqli to‘g‘ridan to‘g‘ri boshlang‘ich masalalarni sonli yechishda ham qo‘llaniladi. Bir vaqtning o‘zida qo‘zg‘almas to‘rlarni qo‘llaydigan usullardan (sonli farqlash amalga oshirilmaydi) va xarakteristikalar usuli kabi usullardan (hisoblash siniq chiziqlar bo‘ylab emas, balki to‘g‘ri chiziqlar bo‘ylab amalga oshiriladi) afzalliklarga ega. Bundan tashqari, bu usul, i.u. uchun natijalardan foydalanganligi sababli, kafolatlangan natijalarni olish uchun qulayroqdir.

Maqolaning umumiy sxemasi tuzilgan. har qanday tartibdagi differensial operatorlar tarkibiga ega bo‘lmagan chiziqli operator-differensial tenglamalar uchun boshlang‘ich masalalarning keng sinfini o‘rganishda. Ushbu

sxemaning ikkinchi, uchinchi, to‘rtinchi va ixtiyoriy tartibli har xil turdagi tenglamalar uchun qo‘llanilishi ko‘rsatilgan, oxirida u ko‘p fazoviy o‘zgaruvchilarga ega bo‘lgan tenglamalar uchun umumlashtiriladi. Alohida misollar uchun, ko‘rsatilganidek, xarakteristikalar usulini qo‘llash mumkin bo‘lmagan hollarda ham yechimlar konvergent qatorlar shaklida olinadi.

Birinchi tartibli chiziqli bo‘lmagan qisman differentsial tenglamalar tizimini xarakteristikalar usuli bilan o‘rganish, har doim noma’lum funksiyalarning superpozitsiyasi mavjud bo‘lgan integral tenglamalarning chiziqli bo‘lmagan tizimini o‘rganishga qisqartiriladi. Va xarakterli o‘zgaruvchilarda yechim topib, asl muammoning yechimini olish uchun xarakterli o‘zgaruvchilardan asl o‘zgaruvchilarga o‘tish kerak. Oxirgi masala ko‘p hollarda shunchalik murakkabki, u hal etilmaydi, lekin shart sifatida o‘zgaruvchilarning teskari o‘zgarishining maqbulligi qabul qilinadi.

ADABIYOTLAR TAHLILI VA METODLAR

M.I. Imanaliev o‘zining “Qisman hosilali nochiziqli integrodifferensial tenglamalar” asarida “shartlanuvchi xaritalar” tamoyili asosida ishlab chiqilgan maqoladan foydalangan holda, qisman hosilalardagi turli nochiziqli differensial tenglamalar o‘qdagi dastlabki shartlar bilan integral tenglamalarga (ya’ni) keltirildi va ba’zi sohalarda mavjudlik va yagonalik uchun yetarli shartlar topildi.

Норкин С. Б.,Карашева К. О нерегулярной осцилляции собственных функций краевой задачи с запаздыванием chiziqli bo‘lmagan ayirmali tenglamalar sistemasi yechimlari va ularning xossalari mavzusi bo‘yicha oldin qilingan ishlar tanishib chiqilgan. *Айзенгендлер П. Г.,ВайнбергМ. М. О Ветвление периодических решений дифференциально-разностных уравнений*larda Chiziqli bo‘lmagan ayirmali tenglamalarni o‘rganishda foydalanildi. *Тураев Х. Исследование непрерывных и периодическых решений систем разностных уравнений.* ishlarda Chiziqli bo‘lmagan ayirmali tenglamalar sistemasi yechimlarining tadbiqlari topilib o‘rganildi.

NATIJALAR VA MUHOKAMA. Birinchi tartibli chiziqli bo‘lmagan qisman differensial tenglamalar tizimini xarakteristikalar usuli bilan o‘rganish, har doim noma’lum funksiyalarning superpozitsiyasi mavjud bo‘lgan integral tenglamalarning chiziqli bo‘lmagan tizimini o‘rganishga qisqartiriladi. Quyidagi ko‘rinishga ega bo‘lgan chiziqli ayirmali tenglamalar sistemani qaraymiz

$$x(t+1) = A(t)x(t) + f(t) + F\big(t, x(t), y(t)\big),$$
$$y(t+1) = B(t)y(t) + \psi(t) + \Phi\big(t, x(t), y(t)\big)$$

Bunda

$$t \in R = (-\infty, +\infty),\ \ A(t) = diag(a_1(t), \dots\dots, a_p(t))$$
$$B(t) = diag(b_1(t), \dots\dots, b_r(t)),\ \ f(t) = diag(f_1(t), \dots\dots, f_p(t)),$$
$$\psi(t) = diag(\psi_1(t), \dots\dots, \psi_r(t))$$
$$F(t,x,y) = \Big(F_1(t,x,y), \dots\dots, F_p(t,x,y)\Big),\ \ \Phi(t,x,y) = \Big(\Phi_1(t,x,y), \dots\dots, \Phi_p(t,x,y)\Big),$$
$$a_i(t), f_i(t), F_i(t,x,y),\quad \text{i=1,....,p},\quad b_j(t), \psi_j(t), \Phi_j(t,x,y),\quad \text{j} = 1, \dots\dots, \text{r},$$

t bo‘yicha T-davrli uzluksiz haqiqiy funksiyalar.

(3.1) sistemaning T-davrli uzluksiz yechimi mavjudligi va yagonaligini tekshirganda quyidagi mulohazalarni qabul qilamiz.

1) Barcha $t \in R$ uchun

$$|a_i(t)| \le \alpha_i < 1 < \beta_j \le |b_j(t)|, \quad i = 1, \dots, p, \qquad j = 1, \dots, r,$$

bo'lgan musbat L_i va β_j mavjud.

2) F(t,x,y), Φ(t,x,y) vektor – funksiyalar quyidagi shartni qanoatlantirsin

$$|F(t,x',y') - F(t,x'',y'')| \le \mathcal{L}_1(|x'| + |x''| + |y'| + |y''|)(|x' - x''| + |y' - y''|),$$

$$|\Phi(t,x',y') - \Phi(t,x'',y'')| \le \mathcal{L}_2(|x'| + |x''| + |y'| + |y''|)(|x' - x''| + |y' - y''|),$$

bunda $\mathcal{L}_1, \mathcal{L}_2 = const > 0$,

$$(t,x',y'), (t,x'',y'') \in D = \{-\infty < t < +\infty, |x| \le \mathrm{d}, |y| \le \mathrm{d}\},$$

va $F(t,0,0) \equiv 0$, $\Phi(t,0,0) \equiv 0$.

Quyidagi tenglamalar sistemani qaraymiz

$$x(t+1) = A(t)x(t) + f(t), \; y(t+1) = B(t)y(t) + \psi(t) \qquad (3.2)$$

Lemma 2.3.1 (3.2) tenglamalar sistema, quyidagi ko'rinishga ega bo'lgan T-davrli uzluksiz yechimga ega

$$\mathcal{S}(t) = \sum_{i=1}^{\infty} \bar{C}_i(t) f(t-1),$$

$$\mathrm{L}(t) = \sum_{i=0}^{\infty} \tilde{c}_i(t) \psi(t+1) \qquad (3.3)$$

bunda $\bar{c}_i(t)$, $i \ge 1$, $\bar{c}_j(t)$, $j \ge 0$ – biror uzluksiz T- davrli matritsalar

Haqiqatdan ham (3.3) ni (3.2) ga qo'ysak

$$\sum_{i=1}^{\infty} \bar{C}_i(t+1) f(t+1-i) = A(t) \sum_{i=1}^{\infty} \bar{C}_i(t) f(t-1) + f(t),$$

$$\sum_{i=1}^{\infty} \bar{C}_i(t+1) \psi(t+1-i) = A(t) \sum_{i=1}^{\infty} \bar{C}_i(t) \psi(t-1) + \psi(t),$$

bundan, agar

$$\bar{c}_i(t+1) = E, \qquad \bar{c}_{i+1}(t+1) = A(t)\bar{c}_i(t),$$
$$B(t)\bar{c}_0(t) + E = 0, \qquad \bar{c}_{i+1}(t+1) = B(t)\bar{c}_i(t),$$

i=1,2,....,

bo'lsa (3.3) qatorlar (3.2) sistemaning formal yechimi bo'lib qoladi.

Oxirgi munosabatlardan

$$\bar{c}_i(t) = E, \quad \bar{c}_{i+1}(t) = \prod_{j=1}^{i} A(t-j),$$

$$\bar{l}_0(t) = -B^{-1}(t), \quad \bar{c}_i(t) = -\prod_{j=1}^{i} B^{-1}(t+j)\ , \qquad i = 1,2,,\dots$$

kelib chiqadi.

Osonlikcha ko‘rsatish mumkin

$$\bar{c}_{i+1}(t) = diag\big(\bar{C}^1{}_{i+1}(t), \dots\dots, \bar{C}^p{}_{i+1}(t)\big),$$
$$\bar{c}_i(t) = diag\big(\bar{}^1{}_{i+1}(t), \dots\dots, \bar{C}^r{}_{i+1}(t)\big)\ \ i = 0,1,\dots$$

bunda $\bar{C}^{j_i}{}_1(t) = 1$

$$\bar{C}^{j_1}{}_{i+1}(t) = \prod_{j=1}^{i} a^{j_1}{}_1(t-j)\,,$$

$j_1 = 1, \dots., p$

$$\bar{C}^{j_1}{}_0(t) = -b^{-1}{}_{j_1}(t)$$
$$\bar{C}^{j_1}{}_i(t) = -\prod_{j=0}^{i} b^{-1}{}_{j_1}(t+j),\ \ j_2 = 1, \dots., r\ \ \ i = 1,2, \dots.$$

Bundan 1) shartga ko‘ra, quyidagi natijaga erishamiz.

$$\left|\tilde{c}^{j_1}{}_i\right| \le \alpha^{i-1}{}_{j_2} \qquad j_1 = 1, \dots., p$$
$$\left|\tilde{c}^{j_1}{}_{i-1}\right| \le \beta^{-i}{}_{j_2}, \qquad j_2 = 1, \dots., r \qquad i = 1,2, \dots$$

Demak (3.3) qatorlar ℵ(t), Ł(t) vektor –funksiyalarga ixtiyoriy $t \in R$ lar uchun tekis yaqinlashadi va ular (3.2) tenglamlar sistemani qanoatlantiradi.

$$a_i(t)\,, \qquad f_i(t),\ \ i = 1, \dots. p\ \ b_j(t)\,, \qquad \psi_j(t), \quad j = 1, \dots. r$$

funksiyalar T-davrli bo‘lganligi uchun ℵ(t) va Ł(t) vektor –funksiyalar ham T-davrli bo‘ladi. Lemma isbotlandi.

$$l_1 = \max_t |f(t)|, \quad l_2 = \max_t |\psi(t)|\,.$$

bo‘lsin

Bu holda (3.3) dan

$$|\aleph(t)| \le M_1 l_1,$$
$$|\text{Ł}(t)| \le M_2 l_2, \tag{3.4}$$

kelib chiqadi, $M_1, M_2 = const > 0$

Teorema 2.3.1 1), 2) shartlar bajarilsin va l_1, l_2 yetarli kichik bo‘lsin. Bu holda (3.1) tenglamlar sistemasini yagona bitta T-davrli uzluksiz yechimi mavjud.

Isbot: (3.1) quyidagicha yozib olamiz

$$x(t) = A(t-1)x(t-1) + f(t-1) + F\big(t-1, x(t-1), y(t-1)\big), \tag{3.5}$$

$$y(t) = B^{-1}(t)y(t-1) + B^{-1}(t)\psi(t) - B^{-1}(t)\Phi\big(t, x(t), y(t)\big),$$

va uning T- davrli yechimini ko'rish uchun ketma–ket taqribiy qiymatlar usulini qo'llaymiz. $x_m(t), y_m(t)$, $m = 0,1,$ ... ...larni quyidagicha aniqlab olamiz.

$$x_0(t) = \text{ﻯ}(t), \qquad y_0(t) = \text{L}(t),$$

$$x_m(t) = A(t-1)x_{m-1}(t-1) + f(t-1) + F\big(t-1, x_{m-1}(t-1), y_{m-1}(t-1)\big),$$
$$y_m(t) = B^{-1}(t)y_m(t-1) + B^{-1}(t)\psi(t) - B^{-1}(t)\Phi\big(t, x_m(t), y_m(t)\big), \quad \text{m=1,2,…} \quad . \tag{3.6}$$

Belgilash kiritamiz: M≥ $max\{M_1, M_2\}$ $l = max\{l_1, l_2\}$
$\prec^* = max\{\prec_i, i = 1 \ldots . p\}$, $\beta_* = max\{\beta_j, i = 1 \ldots . r\}$, (1) shartga ko'ra $\{\prec^* < 1, \beta_* > 1\}$ va faraz qilaylik l shunchalik kichik, M esa shunchalik katta bo'lib quyidagi munosabatlar bajarilsin

$$\begin{gathered} Ml \le d, \\ \alpha^* + \frac{1}{M} + 4M\mathcal{L}_1 l \le 1 \\ \frac{1}{\beta_*} + \frac{1}{M} + 4M\mathcal{L}_1 l \le 1 \\ \alpha^* + 8M\mathcal{L}_1 l \le \theta < 1, \\ \frac{1}{\beta_*} + 8M\mathcal{L}_2 l \le \theta < 1 \end{gathered} \tag{3.7}$$

Boshida $x_m(t), y_m(t)$ ketma–ket yaqinlashishlar D sohadan chiqib ketmasligini ko'rsatamiz , bunda

$$|x_0(t)| = |\text{ﻯ}(t)| \le Ml \le d, \quad |y_0(t)| = |\text{L}(t)| \le Ml \le d,$$

$$x_m(t) \le Ml, \quad y_m(t) \le Ml \tag{3.8}$$

(3.6) ga asoslanib

$$|x_{m+1}(t)| \le |A(t-1)||x_m(t-1)| + |f(t-1)| + |F(t-1, x_m(t-1), y_m(t-1)| \le$$

$$\le \alpha^* Ml + l_1 + \mathcal{L}_1(|x_m(t-1)| + |y_m(t-1)|)^2 \le \alpha^* Ml + l + 4M^2 l^2 \mathcal{L}_1 =$$

$$= Ml\left(\alpha^* + \tfrac{1}{M} + 4M\mathcal{L}_1 l\right) \le Ml,$$

$$|y_{m+1}(t)| \le |B^{-1}(t)||y_m(t+1)| + |B^{-1}(t)||\psi(t)| + |B^{-1}(t)||\Phi(t, x_m(t), y_m(t)| \le$$

$$\leq \frac{1}{\beta_*}Ml + \frac{1}{\beta_*}l_2 + \frac{1}{\beta_*}\mathcal{L}_2(|x_m(t)| + |y_m(t)|)^2 \leq \frac{1}{\beta_*}Ml + \frac{1}{\beta_*}l + 4\frac{1}{\beta_*}M^2l^2\mathcal{L}_2 =$$

$$= Ml\left(\frac{1}{\beta_*} + \frac{1}{M} + 4M\mathcal{L}_1 l\right) \leq Ml,$$

baholash m=1,2….. uchun o‘rinli ekanligini ko‘rsatish mumkin. Faraz qilaylik (3.8) baholash m≥ 0 uchun o‘rinli bo‘lib, bundan esa $x_m(t), y_m(t)$ m=0,1,…. D sohadan chiqib ketmasligi kelib chiqadi.

Endi $\{x_m(t)\},\{y_m(t)\}$ $m = 0,1,\ldots.$ ketma-ketliklar (3.5) shartlarni qanoatlantiruvchi uzluksiz T-davrli v(t), w(t) funksiyalarga tekis yaqinlashinini isbotlaymiz.

$\{x_m(t)\},\{y_m(t)\}$ $m = 0,1,\ldots.$ ketma – ketliklar yaqinlashishini isbotlash uchun

$$|x_0(t)| + \sum_{m=1}^{\infty}\left(x_m(t) - x_{m-1}(t)\right),$$

$$|y_0(t)| + \sum_{m=1}^{\infty}\left(y_m(t) - y_{m-1}(t)\right). \qquad (3.9)$$

qatorlarning yaqinlashishini isbotlash yetarlidir.

Barcha $m \geq 1$ uchun

$$|x_m(t) - x_{m-1}(t)| \leq \widetilde{M}\theta^{m-1}, \qquad |y_m(t) - y_{m-1}(t)| \leq \widetilde{M}\theta^{m-1}, \qquad (3.10)$$

baholash o‘rinli ekanligini ko‘rsatib beramiz bunda $\widetilde{M} = const > 0$

Haqiqatdan ham m=1 da (3.2) , (3.6) ga asosan, quyidagi natijaga erishamiz

$$\begin{aligned}|x_1(t) - x_0(t)| &= \left|A(t-1)x_0(t-1) + f(t-1) + F\left(t-1, x_0(t-1), y_0(t-1)\right) - x_0(t)\right| \\ &= \left|A(t-1)\text{ﯤ}(t-1) + f(t-1) + F\left(t-1, \text{ﯤ}(t-1), \text{L}\cdot(t-1)\right) - \text{ﯤ}(t)\right| \\ &= \left|A(t-1)\text{ﯤ}(t-1) + f(t-1) + F\left(t-1, \text{ﯤ}(t-1), \text{L}\cdot(t-1)\right)\right. \\ &\left. - A(t-1)\text{ﯤ}(t-1) - f(t-1)\right| = |F(t-1, \text{ﯤ}(t-1), \text{L}\cdot(t-1)\,)\,| \\ &\leq \mathcal{L}_1(|\text{ﯤ}(t-1)| + |\text{L}\cdot(t-1)|)^2 \leq 4M^2l^2\mathcal{L}_1 \leq Ml = \widetilde{M}\end{aligned}$$

$$\begin{aligned}|y_1(t) - y_0(t)| &= \left|B^{-1}(t)y_0(t+1) + B^{-1}(t)\psi(t) + B^{-1}(t)\Phi\left(t, x_0(t), y_0(t)\right) - y_0(t)\right| \\ &= \left|B^{-1}(t)\text{L}\cdot(t+1) + B^{-1}\psi(t) + B^{-1}\Phi\left(t, \text{ﯤ}(t), \text{L}\cdot(t)\right) - \text{L}\cdot(t)\right| \\ &= \left|B^{-1}(t)\text{L}\cdot(t+1) + B^{-1}(t)\psi(t) + B^{-1}(t)\Phi\left(t, \text{ﯤ}(t), \text{L}\cdot(t)\right) - B^{-1}(t)\text{L}\cdot(t+1)\right. \\ &\left. - B^{-1}(t)\psi(t)\right| \leq |B^{-1}(t)\Phi(t, \text{ﯤ}(t), \text{L}\cdot(t)\,)\,| \leq \frac{1}{\beta_*}\mathcal{L}_1(|\text{ﯤ}(t)| + |\text{L}\cdot(t)|)^2 \leq 4M^2l^2\mathcal{L}_1 \\ &\leq Ml = \widetilde{M}\end{aligned}$$

bundan esa (3.9) baholash esa o‘rinli ekanligi kelib chiqadi. Induksiya usuli yordamida, Faraz qilaylik (3.10) baholash m-1≥ 0 uchun isbotlangan deb ba shu baholash m-1 dan m ga o‘tganda o‘zgarmaydiganini ko‘rsatamiz. Haqiqatan ham (3.6), (3.7) ga asoasan

$$|x_1(t)-x_0(t)| = \left|A(t-1)x_0(t-1)+f(t-1)+F\big(t-1,x_0(t-1),y_0(t-1)\big)-x_0(t)\right|$$
$$= \left|A(t-1)\text{ﻉ}(t-1)+f(t-1)+F\big(t-1,\text{ﻉ}(t-1),\text{L}\cdot(t-1)\big)-\text{ﻉ}(t)\right|$$
$$= \left|A(t-1)\text{ﻉ}(t-1)+f(t-1)+F\big(t-1,\text{ﻉ}(t-1),\text{L}\cdot(t-1)\big)\right.$$
$$\left.-A(t-1)\text{ﻉ}(t-1)-f(t-1)\right| = |F(t-1,\text{ﻉ}(t-1),\text{L}\cdot(t-1)\,)\,|$$
$$\le \mathcal{L}_1(|\text{ﻉ}(t-1)|+|\text{L}\cdot(t-1)|)^2 \le 4M^2l^2\mathcal{L}_1 \le Ml = \widetilde{M}$$

$$|y_1(t)-y_0(t)| = \left|B^{-1}(t)y_0(t+1)+B^{-1}(t)\psi(t)+B^{-1}(t)\Phi\big(t,x_0(t),y_0(t)\big)-y_0(t)\right|$$
$$= \left|B^{-1}(t)\text{L}\cdot(t+1)+B^{-1}\psi(t)+B^{-1}\Phi\big(t,\text{ﻉ}(t),\text{L}\cdot(t)\big)-\text{L}\cdot(t)\right|$$
$$= \left|B^{-1}(t)\text{L}\cdot(t+1)+B^{-1}(t)\psi(t)+B^{-1}(t)\Phi\big(t,\text{ﻉ}(t),\text{L}\cdot(t)\big)-B^{-1}(t)\text{L}\cdot(t+1)\right.$$
$$\left.-B^{-1}(t)\psi(t)\right| \le |B^{-1}(t)\Phi(t,\text{ﻉ}(t),\text{L}\cdot(t)\,)\,| \le \frac{1}{\beta_*}\mathcal{L}_1(|\text{ﻉ}(t)|+|\text{L}\cdot(t)|)^2 \le 4M^2l^2\mathcal{L}_1$$
$$\le Ml = \widetilde{M}$$

Shunday qilib (3.10) baholash barcha m≥ 1 uchun bajariladi.

(3.10) dan (3.9) qatorlar va shular bilan birgalikda $\{x_m(t)\},\{y_m(t)\}$ $m = 0,1,\ldots$. ketma-ketliklar ham barcha $t \in R$ uchun v(t), w(t) uzluksiz bo'lgan funksiyalarga yaqinlashadi.

$x_m(t), y_m(t)$ funksiyalar T-davrli bo'lganligi uchun (bu (3.6)munosabatdan ko'rinib turadi) v(t), w(t) funksiyalar ham T- davrli bo'ladi.

(3.6) da $m \to \infty$ limitga o'tsak v(t), w(t) funksiyalar (3.5) sistemaning, shu bilan birgalikda (3.1) sistemaning T davrli yechimi ekanligi kelib chiqadi. Teorema isbotlandi.

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