№14 2020

Annali d'Italia

VOL. 1

ISSN 3572-2436

Annali d'Italia (Italy's scientific journal) is a peer-reviewed European journal covering top themes and problems in various fields of science.

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500 copies
Annali d'Italia
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Conclusions. Analysis of current trends in the field of information technology, which are of interest to an increasing number of representatives of the logistics industry allows us to speak about the significant impact on the transformation processes in this industry. Investing in startups that relate not only to purely logistics processes but also to the overall development of production processes and interaction with consumers indicates the significant interest of multinational companies in improving the storage, transportation and service of goods, reducing customer service costs and identifying their needs. In the era of global innovative changes in the society, companies seek to realize all the potential benefits of the effective use of information technology in logistics.

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AN ERROR OF DIGITAL INTEGRATOR OF SEQUENTIAL CARRY INTERPOLATOR IN TASKS OF COMPUTER GRAPHICS

Denysiuk V.
Doctor of Philosophy
Vinnytsya National Agrarian University

Abstract

A study and analysis of features of recreation of segments of straight lines are undertaken after the method of digital differential analyzer in a linear interpolator, the errors of DDA and 2-dimentions linear interpolation are certain with the use of digital integrator of sequential carry.

Keywords: computer graphics, graphic information, line, 2-dimensions linear interpolation, error, digital differential analyzer, digital integrator of sequential carry, pulse rate multipler

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Computer graphics allow to use the most evident presentation of information in a graphic kind in different industries of human activity. Actual enough is a task of choice of facilities of computer graphics, namely devices and facilities recreations of graphic information, that provide necessary quality and fast-acting graphic picture generation without the increase of hardware costs with sufficient authenticity of recreation of graphic information. The most widespread elements of the two-dimensional (2D) and three-dimensional (3D) graphic stages are flat grounds, triangles and segments of straight lines [3, 6]. As a task of recreation of grounds and triangles (both filled by a color and contour [4, 6]) can be broken up on the row of tasks on the recreation of segments of straight lines, then it is possible to consider the segment of straight line the basic element of images.

Raising of task. Among the methods of linear interpolation on the recreation of segments of straight lines most distribution was got by the methods based on the use of digital integrators of sequential carry, and methods that is based on the use of digital integrators of parallel transfer or with the calculation of criterion function, Bresenham's line algorithm (BLA) [3, 4].

Linear interpolation devices, systems of differential equalizations of line based on a decision in a self-reactance kind with the use of digital integrators of parallel transfer, two contain register of increases and two story summators. The module of enumeration of summators equals 2^n, where a n-bit of summators is.

As single increases on coordinates come forward signals of summator repletion signal. The linear interpolator based on the decision of the system of differential equalizations of line in a self-reactance kind with application of digital integrators of sequential carry is contained by two register of increases, two pulse rate multipler (PRM) and general for both integrators counter. Signals of exits of pulse rate multipliers are the signals of single increases on coordinates. Application of integrators of sequential carry brings in an additional error through the unevenness of passing of impulses on the exit of integrator, that can be decreased, for example, using the combined digital integrators. The above-mentioned methods interpolate the arbitrary segment of line for 2^n times, where a n-bit of device is. To increase the fast-acting of linear interpolation, change the capacity of counter of binary multiplier depending on the sizes of coordinate increases or carry out the common increase of co-ordinate increases to normalization of one of them (carry out the change of both coordinate increases aside most significant digits, that the most significant digit of one of coordinate increases coincided with the most significant digit of device).

The feature of BLA-method is an exception of increase operation of functional dependence of X and Y due to the use of step-by-step algorithms that change increase operation in the function of y=f (x) on the step-by-step operations of addition. Interpolation on it method gives a ordinate error that does not exceed the step of discretisation. Well-known BLA-method, that will realize co-ordinate steps as soon as, so diagonal steps [3, 4]. Also there are BLA-methods, that interpolations (not more than 0.5 step of discretisation) give a minimum ordinate error. A method found application with the calculation of two BLA-method functions and side-step less. Methods that will realize two co-ordinate steps are known also.

Research actuality is conditioned by swift development of computer graphics facilities for the recreation of difficult pictures and stages with the large dynamics of image [3,4], in that the various high-performance algorithms of recreation of images elements are widely used with the aim of increase of the productivity and reduction of hardware expenses [3,4].

Analysis of features of digital differential analyzer work.

Digital integrator of sequential carry (DISC) is known, as pulse rate multipler (PRM) [8] and also, as a digital differential analyzer (DDA). The name "pulse rate multipler" arose up in connection with the use of him as a transcoder in frequency.If on the entrance of counter of PRM to give pulse of permanent frequency string, then on the exit of PRM there will be present impulses with a midfrequency, what proportional to the control code.

At the count of impulses amount on going PRM beyond a time that answers beginning and end of period of impulsive sequence domain, there is possible appearance of error on the entrance of counter. An error is related to the unevenness of impulses on a PRM-exit and discrete presentation of count result. Unevenness of passing of impulses on a PRM-exit expressed in that between the following of impulses one is after one on a PRM-exit different intervals at an unchanging control code and even entrance frequency on the entrance of counter. In digital integrators in general and in DISC in particular replacement of integration operation of *x*-function $(x = f(t))$ on the summarization operation of successive values of $x_k(t_k)$-functions. Successive values are set in the discrete points of t_k, thus $t_{k+1}-t_k=\Delta t$; Δt is permanent, does not depend on t_k and proportional single impulses, id est cost of impulses that act on the entrance of integrator equals "1" [1]. The error of DISC equals a difference between the value of initial size of $\boldsymbol{x}$ at ideal implementation of the set operation of recreation and size of $\boldsymbol{x_0}$, got from signals that seem integrator [1].

Digital integrator gives out a value for the calculation of ordinates of functions in discrete points, that is why an error is examined exactly in these points at the integer values of argument that is measured by the number of impulses [1].

The initial state of DISC-counter (CT) equals "0". In the control code register of DISC (RG) the entered number:

$$\Delta x = \sum_{i=1}^{n} 2^{n-i+1} a_{n-i+1} , \qquad (1)$$

where $\boldsymbol{a_i}$ - ***i***-digit of control code register RG.

The number of impulses, mine-out by the *i*-chart of coincidence on the receipt of ***t*** impulses on the entrance of DISC, equals:

$$t_i = ent\left(\frac{t+2^{i-1}}{2^i}\right), \qquad (2)$$

The number of impulses on the DISC-exit equals:

$$x_0 = \sum_{i=1}^{n} t_i a_{n-i+1} . \qquad (3)$$

After the receipt of $\boldsymbol{t=2^n}$ impulses of DISC pass to the initial state. Equalization of line that passes through points ***(0, 0)*** and $\boldsymbol{(2^n, \Delta x)}$:

$$x = \sum_{i=1}^{n} 2^{n-i+1} a_{n-i+1} \cdot t / 2^n . \qquad (4)$$

Thus, the error of integration of DISC equals $\delta_p = x - x_0$ and looks like :

$$\delta_p = \frac{\sum_{i=1}^{n} 2^{n-i+1} a_{n-i+1}}{2^n} \cdot t - \sum_{i=1}^{n} t_i a_{n-i+1} . \qquad (5)$$

A few sources examine the estimation of integration error of DISC (DDA or PRM) - δ_p [1-3,5,7].

For determination of error estimations of DISC-integration (by a bit not more than 32 binary digits) an algorithm was worked out:

```
program err1;
uses printer;
label 10;
var
n1:longint; { n1<=32 }
n2:longint; { (n1<=n2<=32) }
line:integer;
pals:array[1..2,1..32] of longint;
control:array[1..2,1..32] of longint;
ertab:text;
tt:integer;
bb:integer;
nn:real; { nn=1/(2**n), '….. nn=2**(-n) }
sign:integer; { > (-1)**n }
a:array[1..32] of integer;

procedure resetarr(var palsarr,controlarr,rang-
numb);
var
n:integer; { (n1<=n<=n2) }
begin
pals[1,1]:=1; pals[2,1]:=1; pals[1,2]:=3;
pals[2,2]:=3;
pals[1,3]:=5; pals[2,3]:=7; pals[1,4]:=9;
pals[2,4]:=15;
pals[1,5]:=21; pals[2,5]:=27; pals[1,6]:=43;
pals[2,6]:=53;
control[1,1]:=1; control[2,1]:=1; control[1,2]:=3;
control[2,2]:=3; control[1,3]:=5; control[2,3]:=7;
control[1,4]:=9; control[2,4]:=15; con-
trol[1,5]:=21;
control[2,5]:=27; control[1,6]:=53; con-
trol[2,6]:=43;
{*************************}
n:=7;
while n<=n2 do
begin
pals[1,n]:=pals[1,n-2]*2+pals[1,n-1];
pals[2,n]:=pals[2,n-2]*2+pals[2,n-1];
if round(n/2-int(n/2)+0.4)>0 then
begin
control[1,n]:=pals[1,n]; control[2,n]:=pals[2,n];
end
else
begin
control[1,n]:=pals[2,n]; control[2,n]:=pals[1,n];
end;
n:=n+1;
end;
end;
function bindegre(var nf):longint;
{************************ }
var
nnf:longint;
index:integer;
begin
index:=1; nnf:=1;
while index<=n1 do
begin
nnf:=nnf*2; index:=index+1;
end;
bindegre:=nnf;
end; { ************************ }
function recursin(var
nf):real;{*********************************}
procedure ctrlbin(var binarray,ctrlcode,range);{
********* }
var
datbuf:longint;
index:integer;
begin
index:=1;
datbuf:=control[1,n1];
while index<=n1 do
begin
a[index]:=
round((datbuf/2-trunc(datbuf/2))*2;
datbuf:=trunc(datbuf/2);
index:=index+1;
end;
end; { *********************** }
var {***********************************}
e:real;
x,b:longint;
j,i:integer;
begin
ctrlbin(a,control[1,n1],n1);
i:=1; e:=0; x:=pals[1,n1];
while i<=n1 do
begin
j:=1; b:=1;
if a[n1-i+1]<>0 then
begin
while j<=i do
begin
b:=b*2; j:=j+1;
end;
e:=e+(x/b-round(int((x+b/2)/b)))*a[n1-i+1];
end;
i:=i+1;
end;
recursin:=e;
end; {**********************************}
function voronov(var nf):real;
{******************************}
var
buf:real;
begin
buf:=(10+3*(n1-1)+sign*0.5*nn)/18;
voronov:=buf;
end; {**********************************}
function sigov(var nf):real;
{**********************************}
var
buf:real;
begin
buf:=(7+3*n1+sign*2*nn)/18;
sigov:=buf;
end; {***********************************}

function arnstein(var nf):real;
{*********************************}
var
buf:real;
begin
buf:=(126+48*n1+32*sign*nn)/288;
arnstein:=buf;
end; {**********************************}
function dancheev(var nf):real;
{**********************************}
var
buf:real;
begin
buf:=(1+3*(n1-1)+sign*nn*0.5)/9;
```

```
dancheev:=buf;
end; {*********************************}
begin
{*********************************}
writeln;
writeln('--------- turbo pascal /12.12.2020/ ---------');
writeln; writeln('introduce start');
writeln('range date n1');
write ('(1,2,3,...,31) : n1 = '); readln(n1);
writeln;
writeln('introduce stop'); writeln('range date n2');
write ('(n1<=n2<=31) : n2 = '); readln(n2);
writeln; writeln('introduce page');
writeln('line date');
write ('(9<=line) : line = '); readln(line);
writeln;
assign(ertab,'ertab.tab'); rewrite(ertab);
write(ertab, 'result of err0 ');
writeln(ertab,'(turbo pascal /12.12.2020/)');
write(ertab, 'binary rate multiplier ');
writeln(ertab,'max abs errors table');
writeln(ertab);
write(ertab, ' n recursion voronov ');
writeln(ertab,'sigov arnstein dancheev');
writeln(ertab);
bb:=1; tt:=line-8;
resetarr(pals,control,n2);
10: while (n1<=n2)and(tt>=1) do
begin
nn:=1/bindegre(n1); sign:=(-1)*round(trunc(n1/2)+0.5);
writeln(ertab,n1:2,' ', abs(recursin(n1)):3:10,' ',
voronov(n1):3:10,' ', sigov(n1):3:10,' ',
arnstein(n1):3:10,' ', dancheev(n1):3:10);
n1:=n1+1; tt:=tt-1;
end;
writeln(ertab);
writeln(ertab,'end of ',bb:1,' page');
bb:=bb+1;
if n1<=n2 then
begin
writeln(ertab); writeln(ertab,char(12));
writeln(ertab); write(ertab, ' n recursion voronov ');
writeln(ertab, 'sigov arnstein dancheev');
writeln(ertab);
tt:=line-4; goto 10;
end;
writeln(ertab,'end of table');
close(ertab);
end.
```

The result of determination of error estimations of DISC-integration (by a bit not more than 32 binary digits) is given in the table 1.

Table 1.

Error estimations of DISC-integration (n=1÷31)

n	RECURSION	VORONOV	SIGOV	ARNSTEIN	DANCHEEV
1	0.5000000000	0.5555555556	0.5555555556	0.6041666667	0.1111111111
2	0.7500000000	0.7083333333	0.6666666667	0.7152777778	0.4166666667
3	0.8750000000	0.8819444444	0.8611111111	0.9097222222	0.7638888889
4	0.9375000000	1.0520833333	1.0416666667	1.0902777778	1.1041666667
5	1.2187500000	1.2204861111	1.2152777778	1.2638888889	1.4409722222
6	1.3906250000	1.3871527778	1.3819444444	1.4305555556	1.7743055556
7	1.5546875000	1.5546875000	1.5520833333	1.6006944444	2.1093750000
8	1.7226562500	1.7217881944	1.7204861111	1.7690972222	2.4435763889
9	1.8886718750	1.8886718750	1.8880208333	1.9366319444	2.7773437500
10	2.0556640625	2.0553927951	2.0549045139	2.1035156250	3.1107855903
11	2.2221679688	2.2221408420	2.2218967014	2.2705078125	3.4442816840
12	2.3889160156	2.3888481988	2.3887261285	2.4373372396	3.7776963976
13	2.5555419922	2.5555352105	2.5554741753	2.6040852865	4.1110704210
14	2.7222290039	2.7222086589	2.7221679688	2.7707790799	4.4444173177
15	2.8888854980	2.8888821072	2.8888617622	2.9374728733	4.7777642144
16	3.0555572510	3.0555521647	3.0555419922	3.1041531033	5.1111043294
17	3.2222213745	3.2222205268	3.2222154405	3.2708265516	5.4444410536
18	3.3888893127	3.3888878292	3.3888846503	3.4374957614	5.7777756585
19	3.5555553436	3.5555550257	3.5555534363	3.6041645474	6.1111100515
20	3.7222223282	3.7222219573	3.7222211626	3.7708322737	6.4444439146
21	3.8888888359	3.8888887564	3.8888883591	3.9374994702	6.7777775129
22	4.0555555820	4.0555554761	4.0555552377	4.1041663488	7.1111109522
23	4.2222222090	4.2222221825	4.2222220633	4.2708331744	7.4444443650
24	4.3888888955	4.3888888690	4.3888888094	4.4374999205	7.7777777380
25	4.5555555522	4.5555555456	4.5555555158	4.6041666269	8.1111110912
26	4.7222222239	4.7222222164	4.7222221990	4.7708333102	8.4444444329
27	4.8888888881	4.8888888860	4.8888888773	4.9374999884	8.7777777720
28	5.0555555560	5.0555555541	5.0555555498	5.1041666609	9.1111111082
29	5.2222222220	5.2222222215	5.2222222193	5.2708333304	9.4444444430
30	5.3888888890	5.3888888885	5.3888888872	5.4374999983	9.7777777770
31	5.8888888885	5.5555555558	5.5555555564	5.6041666675	10.1111111115

For determination of exact data on the absolute maximal error of DISC (by a bit not more than 32 binary digits) such algorithm was created:

```
program nbm3; {---------- /12.12.2020/ -----------}
uses dos,crt;
const
c0='result of nbm3';
c1='introduce ';
c2='binary rate multiplier maximum abs errors';
c3=' pals--error--code';
label 10,20,30;
var
dy, dymax, xst, xsp:longint;
cc:integer;
ll:integer; { 6<=ll (38) }
x:longint;
k:longint; { (1,2,3,..) }
n, nmax:real;
a:array[1..32] of integer; { dy }
ris:text;
p, q, bb, dd, hh, gg, kk, pp, tt, mm, zz, ii, yy, r:integer;
yk:longint;
h,m,s,f, ph,pm,ps,pf, th,tm,ts,tf, dh,dm,ds,df:word;

procedure binreset(var binarray,date,arline);
var index:integer;

procedure brmerror(var kp,xp,np);
var b:longint;
i,j:integer;

procedure bininc(var binarray,arline);
label bbii;
var index:integer; {dy}

procedure timwrit(var hour,minute,second,sec100:word);
function lzero(w:word):string;
var s:string;
procedure timwritf(var hour,minute,second,sec100:word);
function lzero(w:word):string;
var s:string;

procedure dtimer(var h1,m1,s1,f1,h2,m2,s2,f2,
dhp,dmp,dsp,dfp:word);
var dhb,dmb,dsb,dfb:integer;

begin
{*******************************************
****}
writeln; writeln(c1);
writeln('range date k');
write ('(1,2,3,4,...,k) : k = '); readln(k);
writeln(c1,'start');
writeln('impulses date');
write ('1<=xst<=2**k : xst = '); readln(xst);
writeln;
writeln(c1,'stop');
writeln('impulses date');
write ('xst<=xsp<=2**k : xsp = '); readln(xsp);
writeln;
writeln(c1,'line');
writeln('position date');
write ('18<=cc<=136 : cc = '); readln(cc);
writeln;
writeln(c1,'page');
writeln('line date');
write (' 7<=ll : ll = '); readln(ll);
writeln;
x:=xst;
yk:=round(exp(k*ln(2))+0.5)-1; { (2**k)-1 }
q:=round(ln(k)/ln(10)+0.5);
tt:=ll;
hh:=18;
gg:=trunc(cc/hh);
if (cc-gg*hh)<(gg-1)*2 then
gg:=gg-1;
bb:=1;
zz:=4;
pp:=round((ln((xsp-xst)/(gg*(ll-zz-
2))+1))/(ln(10))+0.5);
r:=round(((xsp-xst+3+1)/((ll-1)*gg)+0.5));
write('number of page is ',r:pp,', ');
gettime(th,tm,ts,tf); write('it is now ');
timwrit(th,tm,ts,tf);
write(', ');
ph:=th; pm:=tm; ps:=ts; pf:=tf;
writeln('start of ',bb:pp,' page');
assign(ris,'ris.tab'); rewrite(ris);
writeln(ris,c0); writeln(ris,c2);
writeln(ris,'range of multiplier k = ',k:q);
writeln(ris);
tt:=tt-zz;
20: kk:=xsp-x;
if kk>=0 then
begin
mm:=round(kk/gg+0.5);
if mm>=(tt-2) then
dd:=tt-2
else
dd:=mm; ii:=gg;
while ii>=1 do
begin
write(ris,c3,' '); ii:=ii-1;
end;
writeln(ris);
tt:=tt-1; yy:=gg;
10: if kk>=0 then
begin
if tt>=1 then
begin
if yy>=1 then
begin
if x<=xsp then
begin
dy:=1; dymax:=0;
binreset(a,dy,k);
n:=0; nmax:=0;
while dy<=yk do
begin
bininc(a,k); brmerror(k,x,n);
if abs(n)>=abs(nmax) then
```

```
begin
nmax:=n; dymax:=dy;
end;
dy:=dy+1;
end;
write(ris,x:5,' '); write (ris,abs(nmax):2:4,' ');
write (ris,dymax:5,' ');
kk:=kk-1; x:=x+dd; yy:=yy-1;
end
else
begin
writeln(ris);
tt:=tt-1; x:=x-(gg-1)*dd+1; gg:=gg-1; yy:=gg;
end;
goto 10;
end
else
begin
writeln(ris);
tt:=tt-1; x:=x-gg*dd+1; yy:=gg;
end;
goto 10;
end
else
begin
write(ris,'end of ',bb:pp,' page, ');
write(ris,'page computating time : ');
gettime(h,m,s,f);
dtimer(ph,pm,ps,pf,h,m,s,f,dh,dm,ds,df);
timwritf(dh,dm,ds,df); { for ris.tab}
write('number of page is ',r:pp,', '); write('it is now
');
timwrit(h,m,s,f);
write(', '); write('end of ',bb:pp,' page, ');
sound(750); delay(500); nosound;
bb:=bb+1;
writeln('start of ',bb:pp,' page');
writeln(ris); { ris.tab }
end;
tt:=ll; x:=x+(gg-1)*dd;
gettime(h,m,s,f);
ph:=h; pm:=m; ps:=s; pf:=f;
goto 20;
end
else
begin
30: writeln(ris);
write(ris,'end of ',bb:pp,' page, ');
write(ris,'page computating time : ');
gettime(h,m,s,f);
dtimer(ph,pm,ps,pf,h,m,s,f,dh,dm,ds,df);
timwritf(dh,dm,ds,df);
write('number of page is ',r:pp,', '); write('it is now
');
timwrit(h,m,s,f);
write(', '); write('end of ',bb:pp,' page');
write(', '); write('end of table');
sound(750); delay(500); nosound;
writeln(ris);
write(ris,'end of table, ', 'table computating time :
');
dtimer(th,tm,ts,tf,h,m,s,f,dh,dm,ds,df);
timwritf(dh,dm,ds,df);
end;
end;
close(ris);
sound(500); delay(1000); nosound;
end.
{*****************************************
****}
```

On fig.1 and table 2 exact data over are brought on the absolute maximal error of DISC.

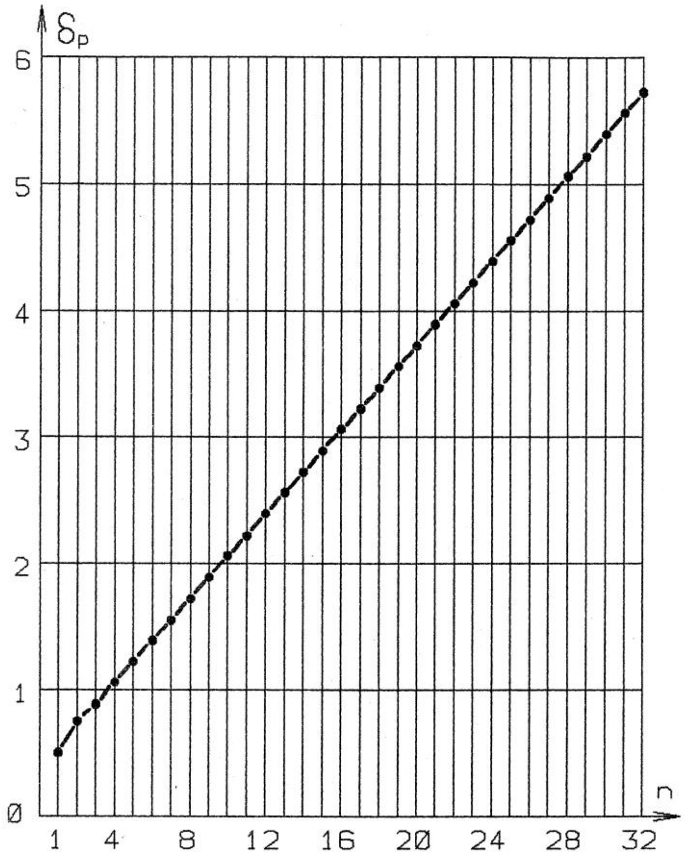


Fig.1. Absolute maximal error of digital integrator of sequential carry

The analysis of the obtained data gives the exact meaning of error of digital integrator of sequential carry for a corresponding bit. It seems on the face of it, that such large error, in comparing to the error of methods and algorithms with a criterion function [3, 4], diminishes to possibility of the use of DISC. But a maximal error for every bit arises up only two times for the cycle of work at corresponding combination control code and amounts of impulses on the entrance of DISC (n>2) (table 2).

Table 2.

Absolute maximal error of digital integrator of sequential carry

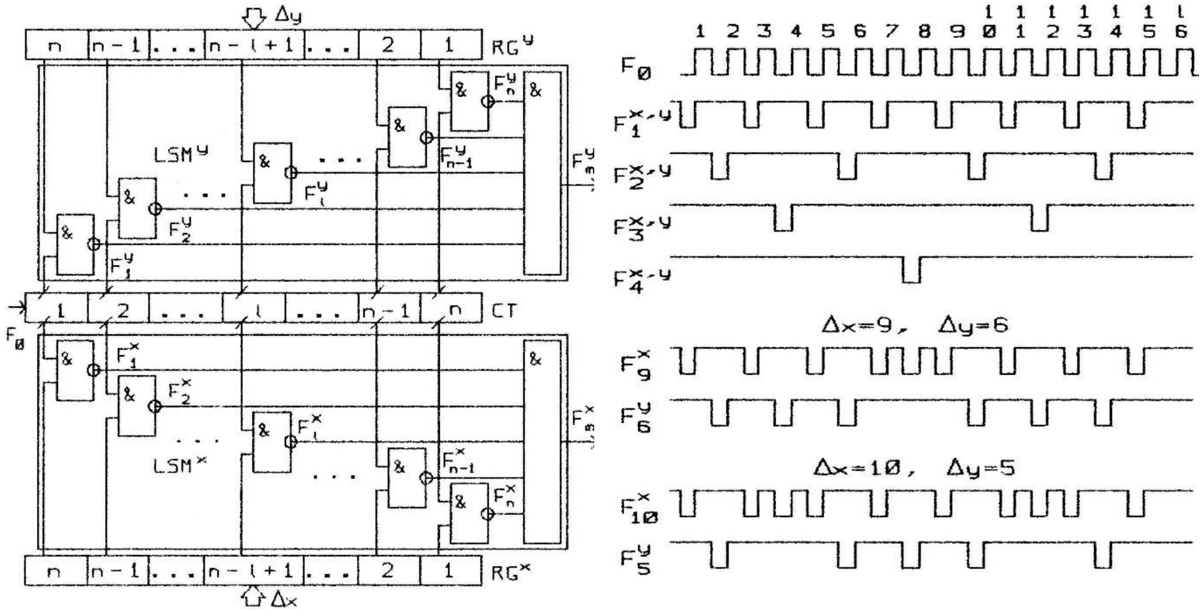
n	Control code β_1^1 or β_1^2																	Entrance impulses x_1^1 x_1^2	Error, δ_p
	Binary																Decimal		
	left-hand digit ———————— first digit																		
1																1	1	1	0.5
2															1	1	3	3	0.75
3														1 1	0 1	1 1	5 7	5 7	0.875
4													1 1	0 1	1 0	1 1	11 13	13 11	1.0625
5												1 1	0 1	1 0	0 1	1 1	21 27	21 27	1.21875
6											1 1	1 0	0 1	1 0	0 1	1 1	53 43	43 53	1.39063
7										1 1	0 1	1 0	0 1	1 0	0 1	1 1	85 107	85 107	1.55469
8									1 1	1 0	0 1	1 0	0 1	1 0	0 1	1 1	213 171	171 213	1.72266
9								1 1	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 1	341 427	341 427	1.88867
10							1 0	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 1	853 683	683 853	2.05566
11						1 1	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 1	1365 1707	1365 1707	2.22217

12					1 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 1	3413 2731	2731 3413	2.38892
13				1 1	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 1	5461 6827	5461 6827	2.55554
14			1 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 1	13653 10923	10923 13653	2.72223
15		1 1	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 1	21845 27307	21845 27307	2.88889
16	1 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 0	0 1	1 1	54613 43691	43691 54613	3.05556

An analysis of features of two-dimensional linear interpolator is on the basis of digital differential analyzer.

Will consider 2D-interpolation of linear function of ***y=f (x)*** on a device that contains two DISC with a general counterr [3].

One of possible variants of such interpolator is brought around on the fig.2, thus, ***X*** comes forward for an abscissa, and ***Y*** comes forward for an ordinate.



a) b)

Fig.2. 2D linear interpolator on two pulse rate multiplers:
a) structure diagram; b) signals diagrams of interpolation example for n = 4.

In the control registers of DISC of interpolator writtenin codes of corresponding coordinate increases: Δ***x*** is a coordinate increase for the ***X***-axes - ***RG***[x], Δ***y*** - for ***Y***-axes - ***RG***[y]:

$$\Delta x = \sum_{i=1}^{n} 2^{n-i+1} a_{n-i+1} ;$$

$$\Delta y = \sum_{i=1}^{n} 2^{n-i+1} b_{n-i+1} , \qquad (6)$$

where a_i and b_i - ***i***-bit of ***RG***[x] or ***RG***[y] corresponding.

Assume that Δ***x*** ≥Δ***y*** and Δ***x*** contains in a most significant digit "1", id est is the normalized quantity.

Initial frequency sequences of coordinate pulse rate multiplers F_m^x and F_m^y are functions of x_0 and y_0 entrance impulsive frequency F_0 on the entrance of general counter.

In other words, amount of impulses x_0 and y_0 on the exit of interpolator after a receipt on the counter entrance of ***t***-impulses of frequency F_0 equals:

$$x_0 = \sum_{i=1}^{n} t_i a_{n-i+1} \; ; \; y_0 = \sum_{i=1}^{n} t_i b_{n-i+1} \; . \; (7)$$

In the total get in a self-reactance kind a function $y_0 = f(x_0)$, that executes approximation of line $y_t = \dfrac{\Delta y}{\Delta x} \cdot t$ in discrete coordinate space ***(xyt).***

For an error 2D linear interpolation a difference is accepted between the value of function $y_t = \dfrac{\Delta y}{\Delta x} \cdot t$ and $y_0 = f(x_0)$ [1].

At a rectangular projection on a plane ***(xOy)*** to the line y_t a self-reactance line, corresponds $y = \frac{\Delta y}{\Delta x} \cdot x$ and the sought after error corresponds δ_0 :

$$\delta_0 = y - y_0 \ . \qquad (8)$$

With taking (7) into account and that in discrete coordinate space an error is examined only at the integer values of argument that is calculated in an amount steps on the coordinate of ***x*** [1, 3, 6], for δ_0 maybe to write (9) down :

$$\delta_0 = \frac{\Delta y}{\Delta x} \cdot x_0 - y_0 = \frac{\Delta y}{\Delta x} \cdot \sum_{i=1}^{n} t_i a_{n-i+1} - \sum_{i=1}^{n} t_i b_{n-i+1} \ . \ (9)$$

On fig.3 it is resulted two examples ($\Delta x = 9$, $\Delta y = 6$ and $\Delta x = 10$, $\Delta y = 5$) of work 2D linear DISC-interpolator, that explains the process of construction of lines and determination of error for *n=4*.

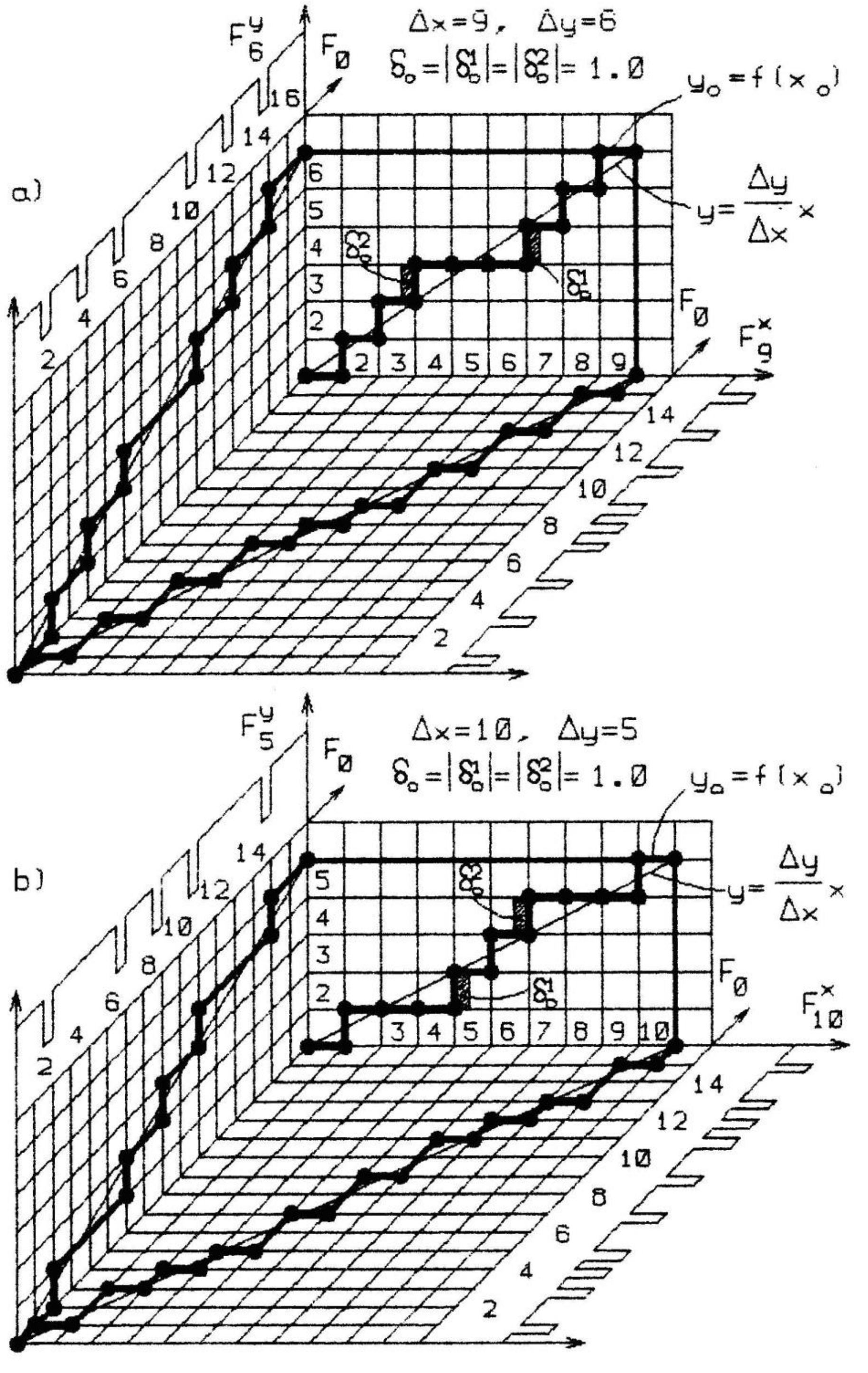


Fig.3. Work 2d linear DISC-interpolator:
a) $\Delta x = 9$, $\Delta y = 6$ ***; b)*** $\Delta x = 10, \Delta y = 5$

For other values of n it exists only for one bets Δx and Δy , that answer a maximal error.

For determination of exact data on the absolute maximal error of linear interpolator by DDA-method (by a bit not more than 32 binary digits) such algorithm was created:

```
program elin1c; {---------- /12.12.2020/ -----------}
uses printer,dos,crt;
label 10,20,30;
var
dx, dy :longint;
a, b:array[1..32] of integer;
n:integer;
t, te:longint;
tb:array[1..32] of integer;
rint:text;
xt, xtold:longint;
ext:real;
yt, ytold:longint;
yet, y0xt, eyxt:real;
ix, iy:integer;
tent:longint;
xp, np:integer;
nn:longint; { 2**n }
dnx:real; { dx/(2**n) }
dny:real; { dy/(2**n) }
datbuf:longint;
j, jjj:integer;
jj:longint;
k:real; { dy/dx }
yy:integer; { y0xt }
l:integer;
h,m,s,f, ph,pm,ps,pf, th,tm,ts,tf, dh,dm,ds,df:word;
emax:array[1..32] of real;
tmax:array[1..32] of longint;
mm, mmm:integer;

function bindegre(nf:integer):longint; {************ }
var
nnf:longint;
index:integer;
begin
if nf>0 then
begin
index:=1; nnf:=1;
while index<=nf do
begin
nnf:=nnf*2; index:=index+1;
end;
bindegre:=nnf;
end
else
bindegre:=1;
end; { ************ }

procedure bintrana(var ap,bufferp,rangep);
var
index:integer;
begin { bintrana(a,datbuf,n) }
index:=1;
while index<=n do
begin
a[index]:=round((datbuf/2-trunc(datbuf/2))*2);
datbuf:=trunc(datbuf/2); index:=index+1; { a[i]-i}
end;
end; { bintrana(a,datbuf,n) }

procedure bintranb(var bp,bufferp,rangep);
var
index:integer;
begin { bintranb(b,datbuf,n) }
index:=1;
while index<=n do
begin
b[index]:=round((datbuf/2-trunc(datbuf/2))*2);
datbuf:=trunc(datbuf/2); index:=index+1;
end;
end; { bintranb(b,datbuf,n) }

procedure timwrit(var hour,minute,second,sec100:word);
{**** timwrit ****}
function lzero(w:word):string;
var
s:string;
begin {-------------- }
str(w:0,s);
if length(s)=1 then s:='0'+s;
lzero:=s;
end; {-------------- }
begin
write(lzero(hour),':', lzero(minute),':',
lzero(second),'.', lzero(sec100));
end; {**** timwrit ****}

procedure timwritf(var hour,minute,second,sec100:word);
{**** timwritf ****}
function lzero(w:word):string;
var
s:string;
begin {-------------- }
str(w:0,s);
if length(s)=1 then s:='0'+s;
lzero:=s;
end; {--------------}
begin
write(rint,lzero(hour),':', lzero(minute),':',
lzero(second),'.', lzero(sec100));
end; {**** timwritf ****}

procedure dtimer(var h1,m1,s1,f1,
h2,m2,s2,f2,
dhp,dmp,dsp,dfp:word);
var
dhb,dmb,dsb,dfb:integer;
begin {**** dtimer ****}
dfb:=f2-f1;
if dfb<0 then
begin
df:=100-f1+f2; dsb:=s2-s1-1;
end
else { f1<=f2 }
```

```
begin
df:=f2-f1; dsb:=s2-s1;
end;
if dsb<0 then
begin
ds:=60-s1+s2; dmb:=m2-m1-1;
end
else
begin
if dfb<0 then
ds:=s2-s1-1
else
ds:=s2-s1;
dmb:=m2-m1;
end;
if dmb<0 then { m1>m2 }
begin
dm:=60-m1+m2; dhb:=h2-h1-1;
end
else { m1<=m2 }
begin
if dsb<0 then
dm:=m2-m1-1
else
dm:=m2-m1;
dhb:=h2-h1;
end;
if dhb<0 then { h1>h2 }
dh:=12-h1+h2
else { h1<=h2 }
if dmb<0 then
dh:=h2-h1-1
else
dh:=h2-h1;
end; {**** dtimer ****}

begin
writeln;
writeln('-------- /12.12.2020/ --------');
writeln('32 max errors of bin rate multipliers line interpolator');
writeln;
writeln('introduce interpolation range');
writeln('(1<=n<=16)');
write ('n = '); readln(n); { n }
writeln;
nn:=bindegre(n); { 2**n }
writeln('introduce delta x');
writeln('(',bindegre(n-1):5,'<=dx<=',(nn-1):5,')');
write ('dx = '); readln(dx); { delta x }
writeln;
xp:=round(ln(dx)/ln(10)+0.5); { dx }
np:=round(ln(n)/ln(10)+0.5); { n }
dnx:=dx/nn;
writeln('introduce delta y');
writeln('(0<=dy<=dx)');
write ('dy = '); readln(dy); { delta y }
writeln;
gettime(th,tm,ts,tf); write('it is now '); timwrit(th,tm,ts,tf);
ph:=th; pm:=tm; ps:=ts; pf:=tf;
writeln(', start of table');
dny:=dy/nn; k:=dy/dx; t:=1; te:=bindegre(n);
j:=1;
while j<=32 do
begin
emax[j]:=0; tmax[j]:=0; j:=j+1; { 32 }
end;
datbuf:=dx;
bintrana(a,datbuf,n);
datbuf:=dy;
bintranb(b,datbuf,n); { b[i..n] }
assign(rint,'rint.tab'); { rint.tab }
rewrite(rint);
writeln(rint,
'result of elin1c ',
'(/12.12.2020/)');
if te>=32 then
write(rint,'32')
else
write(rint,te:(round(ln(te)/ln(10)+0.5)));
writeln(rint,' max errors of ', 'binary rate multipliers ',
'line interpolator ');
writeln(rint);
writeln(rint,'range of interpolator n = ',n:np);
write(rint,'delta x = [',dx:xp,']10 = [');
j:=n; { delta x }
while j>=1 do
begin
write(rint,a[j]:1);
j:=j-1;
end;
writeln(rint,']2, [h-l]2');
write(rint,'delta y = [',dy:xp,']10 = [');
j:=n; { delta y }
while j>=1 do
begin
write(rint,b[j]:1);
j:=j-1;
end;
writeln(rint,']2, [h-l]2');
writeln(rint);
xtold:=0; ytold:=0;
while t<=te do
begin
j:=1; xt:=0; yt:=0;
while j<=n do
begin
jjj:=n-j+1; jj:=bindegre(j); tent:=trunc(int((t+jj/2)/jj));
if a[jjj]<>0 then
xt:=xt+tent*a[jjj];
if b[jjj]<>0 then
yt:=yt+tent*b[jjj];
j:=j+1;
end;
ext:=dnx*t-xt;
eyt:=dny*t-yt;
y0xt:=k*xt;
eyxt:=y0xt-yt;
if xt>xtold then
ix:=1
else
ix:=0;
if yt>ytold then
```

```
iy:=1
else
iy:=0;
xtold:=xt;
ytold:=yt;
mm:=1; { ****************** }
20: if mm<=32 then
begin
if abs(eyxt)>=abs(emax[mm]) then
begin
mmm:=32;
while mmm>=mm do
begin
emax[mmm]:=emax[mmm-1];
tmax[mmm]:=tmax[mmm-1];
mmm:=mmm-1;
end;
emax[mm]:=eyxt; tmax[mm]:=t; { 32 }
goto 30;
end;
mm:=mm+1;
goto 20;
end; { ****************** }
30: t:=t+1;
end;
writeln(rint,'maximum error input pulses');
mm:=1;
while mm<=32 do
begin
if emax[mm]<0 then
write(rint,'-',(abs(emax[mm])):2:10,' ')
else
write(rint,' ',emax[mm]:2:10,' ');
write(rint,' ');
writeln(rint,tmax[mm]:5);
if mm>=te then
goto 10;
mm:=mm+1;
end;
10: gettime(h,m,s,f);
ph:=h; pm:=m; ps:=s; pf:=f;
write('it is now '); timwrite(h,m,s,f);
writeln(', end of table');
write(rint,'end of table, ', 'table computating time:');
dtimer(th,tm,ts,tf,h,m,s,f,dh,dm,ds,df);
timwrite(dh,dm,ds,df); { rint.tab}
close(rint);
sound(750); delay(500); nosound;
sound(500); delay(1000); nosound;
end.
```

As well as expected [1], maximal error at the construction of line on DISC-linear interpolator arises up a two times, one time with a sign "-": $-\delta_0 = \delta_0^1$; second time with a sign "+": $+\delta_0 = \delta_0^2$.

Using expression (9) the got values of error δ_0 for $n = \overline{1,5}$.

With the use of principle of mathematical induction the iteration algorithm of receipt of values Δx_i, Δy_i, $C_i^{1,2}$ and corresponding to them values δ_0 are built for the different *i*-values ($i = \overline{1,n}$) of interpolator ($C_i^{1,2}$ is a number of impulses on the entrance of frequency counter CT, C_i^1 corresponding "$-\delta_0$", and C_i^2 corresponding "$+\delta_0$").

The ітеративний algorithm of determination of values Δx, Δy, $C_i^{1,2}$ and maximal error (δ_0^1 and δ_0^2) of 2D- linear DISC-interpolator works as follows:

1) to set the initial value of ***i=5***;
2) to set the value ***x*** and ***y*** of control code in the well-known initial state (Δx_i, Δy_i, $\Delta x_i \geq \Delta y_i$); and C_i^1, C_i^2 - corresponding values of amount of impulses are on the counter entrance, at that there is a maximal error of presentation of the real line in discrete *i*-bit coordinate space;
3) to execute the increase of ***i*** on "1";
4) if i – even, then $\Delta x_i = 2 \cdot \Delta x_{i-1}$, $\Delta y_i = 2 \cdot \Delta y_{i-1} + 1$, $C_i^1 = C_{i-1}^1$, $C_i^2 = C_{i-1}^2 \cdot 4 - 2$;
   if i – odd, then $\Delta x_i = 2 \cdot \Delta x_{i-1} + 1$, $\Delta y_i = 2 \cdot \Delta y_{i-1}$, $C_i^1 = C_{i-1}^1 \cdot 4 + 5$, $C_i^2 = C_{i-1}^2$;
5) to calculate δ_0^1 and δ_0^2 on a formula (9);
6) if to continue a calculation, then on a point 3, otherwise is an end.

On the basis of algorithm there were certain Δx_i, Δy_i, $C_i^{1,2}$ and also values of absolute maximal error δ_0 (9) of 2D-linear PRM-interpolator for $i = \overline{2,32}$. The got results are driven to the table 2 and tables 3.

Results of error estimation of 2D linear interpolator correlated with a well-known estimation [1, 7], after that a maximal error of interpolator is on two DISC satisfies to expression:

$$\frac{n}{4} < |\theta_{\max}| \leq \frac{n}{3}, \qquad (10)$$

where ***n*** – amount of interpolator digits.

By means of an offer algorithm data are got about the absolute maximal error of 2D-linear DISC-interpolator, that is presented in a table 3, table 4 and on fig.5.

Table 3.

Error of 2D-linear DISC-interpolator (n=2÷16)

n	Δx, Δy		Number of impulses C_i^1, C_i^2		Error δ_0
	Binary left-hand digit---first digit	Decimal	Binary left-hand digit---first digit	Decimal	
2	10 01	2 1	1 10	1 2	0.5
3	100 011	4 3	001 110	1 6	0.75
4	1001 0110	9 6	1001 0110	9 6	1.0
	1010 0101	10 5	0101 1010	5 10	1.0
5	10010 01101	18 13	01001 10110	9 22	1.3333
6	100101 011010	37 26	101001 010110	41 22	1.5676
7	1001010 0110101	74 53	0101001 1010110	41 86	1.9054
8	10010101 01101010	149 106	10101001 01010110	169 86	2.1409
9	100101010 011010101	298 213	010101001 101010110	169 342	2.4765
10	1001010101 0110101010	597 426	1010101001 0101010110	681 342	2.7136
11	10010101010 01101010101	1194 853	01010101001 10101010110	681 1366	3.0477
12	100101010101 011010101010	2389 1706	101010101001 010101010110	2729 1366	3.2855
13	1001010101010 0110101010101	4778 3413	0101010101001 1010101010110	2729 5462	3.6191
14	10010101010101 01101010101010	9557 6826	10101010101001 01010101010110	10921 5462	3.8571
15	100101010101010 011010101010101	19114 13653	010101010101001 101010101010110	10921 21846	4.1905
16	1001010101010101 0110101010101010	38229 27306	1010101010101001 0101010101010110	43689 21846	4.4285

Table 4.

Error of 2D-linear DISC-interpolator (n=17÷32)

n	Coordinate increases		Number of impulses		Error
	Δx	Δy	C_i^1	C_i^2	δ_0
17	76458	54613	43689	87382	4.7619
18	152917	109226	174761	87382	5.0000
19	305834	218453	174761	349526	5.3333
20	611669	436906	699049	349526	5.5714
21	1223338	873813	699049	1398102	5.9048
22	2446677	1747626	2796201	1398102	6.1429
23	4893354	3495253	2796201	5592406	6.4762
24	9786709	6990506	11184809	5592406	6.7143
25	19573418	13981013	11184809	22369622	7.0476
26	39146837	27962026	44739241	22369622	7.2857
27	78293674	55924053	44739241	89478486	7.6190
28	156587349	111848106	178956969	89478486	7.8572
29	313174698	223696213	178956969	357913942	8.1904
30	626349397	447392426	715827881	357913942	8.4287
31	1252698794	894784853	715827881	1431655766	8.7622
32	2505397589	1789569706	2863311524	1431655766	9.0005

Conclusions. The conducted analysis of recreation features of straight lines segments by the DDA-method allowed exactly to define errors of DDA and 2D-linear DISC-interpolation. Depending on an application of various devices of interpolation domain in facilities of computer graphics it is possible to accept the argued decisions about possibility of the use of DDA-method in 2D-linear interpolation with corresponding hardware costs and fast-acting. Possibly the use of algorithm 2D interpolators of straight lines segments by the DDA-method with requirements to exactness in certain industry of the use. For example, in the real-time systems, imitators, in animation, in trainers that require a maximal fast-acting at the change of image, id est at presence of dynamic images without hard requirements to exactness of image recreation. Summators hardware cost exceeds of digital integrator of sequential carry considerably. Thus, methods with the use of summators not always can satisfy to the requirements of dynamics of difficult images at a minimum of hardware cost [3]. It leads to possibility of necessity of other methods use, namely methods on the basis of DDA, where a fast-acting is determined by the counter microoperation in the least significant bit of counter.

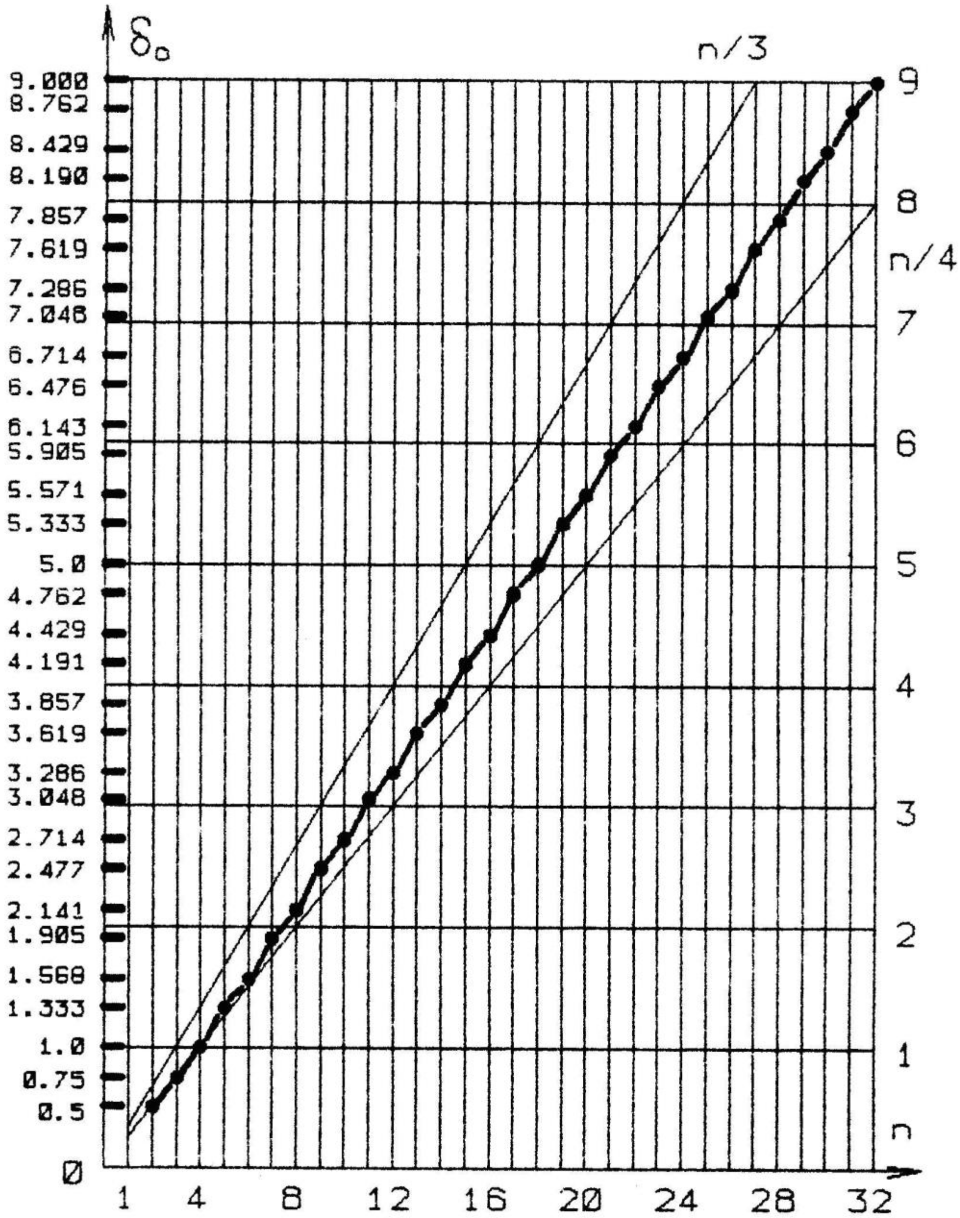


Fig.5. Absolute maximal error of 2D-linear DISC-interpolator

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WAYS TO INTENSIFY THE COLLECTION SEED OF HERBARES

Spirin A.,
Ph.D., Associate Professor
Tverdokhlib I.,
Ph.D., Associate Professor
Omelianov O.,
assistant
Vovk V.
graduate student
Vinnytsia National Agrarian University, Vinnytsia

Abstract

The main technical means for harvesting grass seeds are combine harvesters. But significant differences in the physical and mechanical properties of the seed heap from cereals complicate their work, especially the operations of wiping and separation of seeds. This encourages the search for seedlings to search for and develop new technological and technical solutions for the processes of threshing, wiping and separation of seeds in the field and in the full-time department.

One of the main problems in threshing and wiping the seed heap is the need to recycle the mass to increase the yield of pure seeds. One of the options to reduce the recycling of material in the thresher of the combine is to refine the design of the threshing machine and air-sieve cleaning, which are described in the work.

The results are stated of the research on substantiation of rational modes of operation of technical means at harvesting of seeds of perennial grasses.

The results of research on the process of harvesting grass seeds by combine harvesters reveal the need to intensify the process of wiping the seeds with a threshing machine. One way to solve this problem is to reduce the degree of contamination of the seed heap with straw impurities.

Keywords: combine harvester, harvesting technology, vibrating grille cleaning, threshing machine

Formulation of the problem. For harvesting legume seeds are mainly used combine harvesters, which are the main technical means. Since there are no special machines for harvesting seeds of perennial legumes, all known technologies are based on the use of combine harvesters. As an object of processing, grass seeds have a number of specific features other than cereals in the structure of plants, inflorescences and seeds, which causes significant differences in physical, mechanical and technological properties of the material being processed. Significant differences in the physical and mechanical properties of the biological mass of grass seeds from cereals complicate the process of seed collection and especially the operation of wiping and separation of seeds with a combine thresher. To harvesting grass seeds, combine harvesters use special devices (adapters), which are more suitable for working with such material as a pile of grass seeds. This reduces losses, but still seed losses remain significant and amount to 20-30% of the biological yield.

The process of wiping seeds from beans remains a problematic issue in the work of threshing machines of grain harvesters, the percentage of wiped seeds after passing through the threshing machine is only 45-55%. Therefore, to wipe the rest of the seeds from the beans, the fraction of ungrained seeds is fed into autonomous graters, the efficiency of which is too low, for one pass of material through the grater wipes only 10-15% of the seeds. In addition, due to the low adaptation of air-sieve cleaning to work with a heap of grass seeds, a significant part of straw impurities and chaff is fed into the grater device with not wiped seeds. Repeated feeding of the same material in the grater device for re-wiping the seeds from the beans leads to the recirculation of the material in the thresher of the combine. This leads to overloading of the working bodies of the thresher, and even greater deterioration of the air-sieve cleaning, and, accordingly, to an increase in the loss of seeds behind the threshing machine of the combine. Significant seed losses during the harvesting of grass testicles lead to the need to find and develop new technological and technical solutions for the processes of threshing, wiping and separation of seeds in the field and in the full-time department.

Analysis of recent research and publications. The issue of development of technologies and means of mechanization of harvesting seeds of perennial legumes was paid attention in [1, 2, 3], but it should be noted that these results have significant contradictions and are in the nature of DCR and GDR and do not provide answers on how to reduce seed losses based on the actual production capacity, given the technical means

№14 2020
Annali d'Italia
VOL. 1

ISSN 3572-2436

The journal is registered and published in Italy.
Articles are accepted each month.
Frequency: 12 issues per year.
Format - A4 All articles are reviewed
Free access to the electronic version of journal

500 copies
Annali d'Italia
50134, Via Carlo Pisacane, 10, Florence, Italy
email: info@anditalia.com
site: https://www.anditalia.com/