Use of Computer-Generated Animation Films In The Teaching of Physics

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1. Introduction

There is no doubt that the best way to teach physics in undergraduate universities as well as secondary schools is to have students conduct experiments themselves or for the teachers to do lecture demonstrations.

However, there are many kinds of physical phenomena in which such direct experiments are very difficult or even impossible to conduct. Among these phenomena we can find, first of all, motions under universal gravitation, if we mean by experiments actual observation of physical phenomena, not model-like experiments. Other examples are motion of projectiles with air resistance, which is, for example, proportional to the square of the velocity, classical Rutherford scattering, motion of a particle under central forces of various kinds, etc.

Fortunately, electronic computers, especially those with plotters or display tubes can provide a good means of generating various kinds of motion with various kinds of parameters and initial conditions.

IBM 1130 Continuous System Modeling Program (CSMP) is most fitted for the purpose. Time marks with adjustable equal time intervals can be put on the orbits. These marks make it

1) The basic idea of this paper was presented at the international conference on physics education, International Union On Pure And Applied Physics, held in Eger, Hungary, Sept. 11-17, 1970. Several films Were also shown at the conference.

convenient for us to make an animated films of the motion.

Color films can provide more information than monochromatic ones. Since it is impossible to make color films from the images on cathode ray display tubes, use was made of plotters, not display tubes, and we resorted to manual labor in order to put colors on the pictures.

2. Description of the Procedure

To describe the whole procedure, the case of the motion of an artificial satellite will be shown. The orbit of a satellite can be given analytically. However, the position of the satellite as function of time can only be given implicitly and it is customary that only expressions which give implicitly the relationship between the positions and time are shown. By the use of CSMP one can have the positions of satellite as function of time in the most explicit way.

The gravitational force f between the earth and the satellite is given by

$$f=G\frac{Mm}{r^2}, \tag{1}$$

where G is the gravitational constant $=6.670\times10^{-11}\frac{\mathrm{Nm}^2}{\mathrm{kg}^2}$, M is the mass of the earth, m the mass of the satellite, and r is the distance between the earth and the satellite.

With no lack of convenience, we can put

$$GM=1,$$

by changing the values of the units.

The equations of motion of the satellite is given by

$$\frac{dx}{dt}=u,$$

$$\frac{dx}{dt}=v,$$

$$\frac{du}{dt}=-\frac{x}{(x^2+y^2)^{3/2}},$$

$$\frac{dv}{dt}=-\frac{x}{(x^2+y^2)^{3/2}}.$$

These equations are first converted into a block diagram, which can be constructed in a similar way as in cases of analog computers. Each of the blocks is converted into a punched card with the block number, kind of operation, and the input or inputs. The initial conditions and parameter are also given by punched cards.

3. An Example: Cospar 1970 11A (Oosumi)

As an example the Cosper 1970 11A, which is also called Oosumi and is the first artificial satellite launched by Japanese scientists is calculated and animated.

According to NASA, the data for this artificial satellite is as follows:

Perigee	328 km
Apogee	5164 km
Period	2 h 24 min
Angle with the equator	30°.1
Eccentricity	0.26502

First the orbit was computed by FORTRAN IV procedure, whose program is shown by Table 1. The fourth order Runge-Kutta approximation method is employed in the integration of the differential equations.

The CSMP configuration and initial conditions-parameters are shown by Table 2. The orbit of Cosper 1970 11A (Oosumi) as drawn on the Plotter sheet is shown by Fig. 1. The motion was then animated and a 8-mm loop film for this satellite was made.

Table 1.

```
C     MOTION OF ARTIFICIAL SATELLITE FROM THE VALUES OF PERIGEE AND      SATEL 10
C     APOGEE    A.HARASHIMA  SEPT. 1969                                  SATEL 20
C
C                               OOSUMI
C
C     PER IS THE MIN DIST OF SATELLITE FROM EARTH SURFACE GIVEN IN KM    SATEL 30
C     APO IS THE MAX DIST OF SATELLITE FROM EARTH SURFACE GIVEN IN KM    SATEL 40
      READ(2,10)  PER, APO
   10 FORMAT(2E20.3)
      R0 = 1 + PER / 6378.                                               SATEL 70
      R1 = 1 + APO / 6378.                                               SATEL 80
      V0 = ( 2. * R1 / R0 / ( R0 + R1 ) )**0.5                           SATEL 90
      PERIO = 6.2832 * ( 0.5 * ( R0 + R1 ) )**1.5                        SATEL100
C     H AND PRINT ARE INTEGRATION INTERVAL AND PRINT INTERVAL PRINT IS   SATEL110
C     H AND PRINT ARE INTEGRATION INTERVAL AND PRINT INTERVAL PRINT IS   SATEL110
C     AN INTEGRAL MULTIPLE OF H                                          SATEL111
      READ(2,20) H,PRINT
   20 FORMAT ( 2F10.0 )                                                  SATEL130
      WRITE ( 3,100 )  H, PRINT                                          SATEL140
  100 FORMAT ( 1H0,'INTEG INTERVAL =',F7.3, 4X,'PRINT INTERVAL =',F7.3 )SATEL145
      WRITE(3,200) PER,APO,R0,R1,V0, PERIO
  200 FORMAT ( 1H0,2X,'PER=',F10.4, 2X,'APO =',F15.4, 2X,'R0=',F10.4, 2XSATEL160
     1,'R1=',F10.4, 2X,'V0=',F10.4, 2X,'PERIO=',F10.4 )                  SATEL161
C     INTEGRATION IS CONDUCTED BY RUNGE-KUTTA FOURTH ORDER APPROXIMATIONSATEL170
      WRITE ( 3,300 )                                                    SATEL180
  300 FORMAT ( 1H0,13X,'TIME',14X,'X',14X,'Y',14X,'R' )                  SATEL190
      T = 0.                                                             SATEL200
      X = R0                                                             SATEL210
      Y = 0.                                                             SATEL220
      R = R0                                                             SATEL230
      U = 0.                                                             SATEL240
      V = V0                                                             SATEL250
      WRITE ( 3,400 )  T, X, Y, R                                        SATEL260
  400 FORMAT ( 1H ,10X,F10.4,3( 5X,F10.7 ) )                             SATEL270
      N = PERIO / PRINT + 1.                                             SATEL280
      M = PRINT / H                                                      SATEL285
      DO 1  I = 1 , N                                                    SATEL290
      DO 2  J = 1 , M                                                    SATEL300
      D1 = H * U                                                         SATEL310
      E1 = H * V                                                         SATEL320
      F1 = -H * X / ( X**2. + Y**2. )**1.5                               SATEL330
      G1 = -H * Y / ( X**2. + Y**2. )**1.5                               SATEL340
      D2 = H * ( U + .5 * F1 )                                           SATEL350
      E2 = H * ( V + .5 * G1 )                                           SATEL360
      F2 = -H * ( X + .5 * D1 ) / ( ( X + .5 * D1 )**2. + ( Y + .5 * E1 SATEL370
     1)**2. )**1.5                                                       SATEL371
      G2 = -H * ( Y + .5 * E1 ) / ( ( X + .5 * D1 )**2. + ( Y + .5 * E1 SATEL380
     1)**2. )**1.5                                                       SATEL381

      D3 = H * ( U + .5 * F2 )                                           SATEL390
      E3 = H * ( V + .5 * G2 )                                           SATEL400
      F3 = -H * ( X + .5 * D2 ) / ( ( X + .5 * D2 )**2. + ( Y + .5 * E2 SATEL410
     1)**2. )**1.5                                                       SATEL411
      G3 = -H * ( Y + .5 * E2 ) / ( ( X + .5 * D2 )**2. + ( Y + .5 * E2 SATEL420
     1)**2. )**1.5                                                       SATEL421
      D4 = H * ( U + F3 )                                                SATEL430
      E4 = H * ( V + G3 )                                                SATEL440
      F4 = -H * ( X + D3 ) / ( ( X + D3 )**2. + ( Y + E3 )**2. )**1.5    SATEL450
      G4 = -H * ( Y + E3 ) / ( ( X + D3 )**2. + ( Y + E3 )**2. )**1.5    SATEL460
      U = U + ( F1 + 2. * F2 + 2. * F3 + F4 ) / 6.                       SATEL470
      V = V + ( G1 + 2. * G2 + 2. * G3 + G4 ) / 6.                       SATEL480
      X = X + ( D1 + 2. * D2 + 2. * D3 + D4 ) / 6.                       SATEL490
      Y = Y + ( E1 + 2. * E2 + 2. * E3 + E4 ) / 6.                       SATEL500
      R = SQRT ( X**2. + Y**2. )                                         SATEL510
      T = T + H                                                          SATEL520
    2 CONTINUE                                                           SATEL530
      WRITE ( 3,400 )  T, X, Y, R                                        SATEL540
    1 CONTINUE                                                           SATEL550
      STOP                                                               SATEL560
      END                                                                SATEL570

FEATURES SUPPORTED
 ONE WORD INTEGERS
 EXTENDED PRECISION
 IOCS

CORE REQUIREMENTS FOR
 COMMON      0  VARIABLES     106  PROGRAM     826

 END OF COMPILATION

// XEQ                                                                   SATEL
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Table 2.

CONTINUOUS SYSTEM MODELING PROGRAM
A DIGITAL ANALOG SIMULATOR PROGRAM FOR THE IBM 1130

KEY IN THE 6 DIGITS DATE. 2 FOR MONTH,2 FOR DAY, 2 FOR YEAR
022670
EXTENDED BY T. OSHIMA FOR TOTAL BLOCK NUMBER 150, FUNCTION GENERATOR 6,
INTEGRATOR 50.

CONFIGURATION SPECIFICATION

OUTPUT NAME	BLOCK	TYPE	INPUT 1	INPUT 2	INPUT 3
XCOOD	1	I	4	0	0
UDOT NEG	2	/	1	13	0
UDOT	3	-	2	0	0
U	4	I	3	0	0
YCOOD	5	I	8	0	0
VDOT.NEG	6	/	5	13	0
VDOT	7	-	6	0	0
V	8	I	7	0	0
XSQU	9	X	1	1	0
YSQU	10	X	5	5	0
RSQU	11	+	9	10	0
R	12	H	11	0	0
RCUBE	13	X	11	12	0

INITIAL CONDITIONS AND PARAMETERS

IC/PAR NAME	BLOCK	IC/PAR1	PAR2	PAR3
INIT X	1	1.0000	0.0000	0.0000
INIT U	4	0.0000	0.0000	0.0000
INIT Y	5	0.0000	0.0000	0.0000
INIT V	8	1.0000	0.0000	0.0000

( ) INTEGRATION INTERVAL
0.001

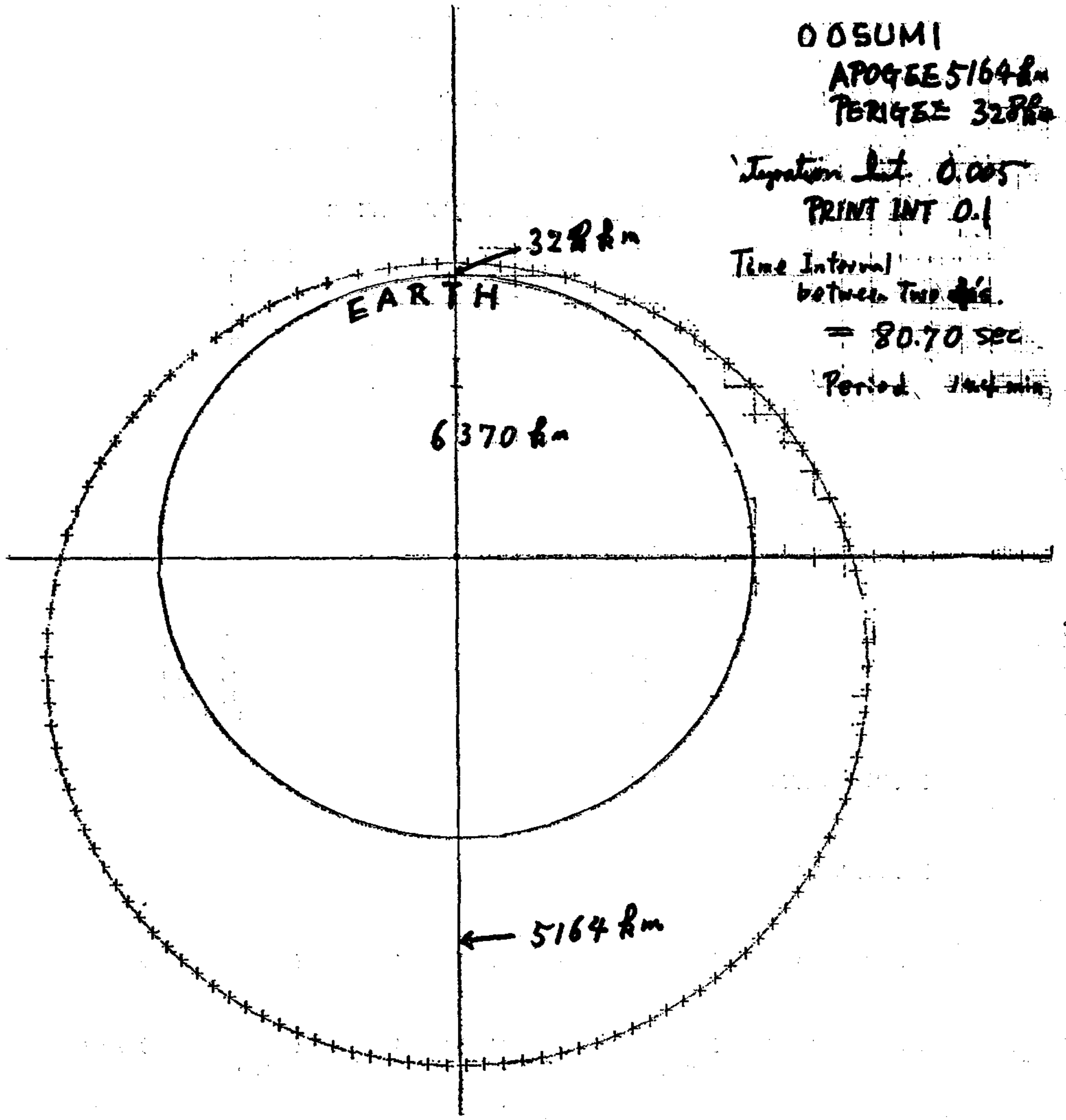
( ) TOTAL TIME
100.

( ) BLOCK FOR Y-AXIS ( ) MINIMUM VALUE ( ) MAXIMUM VALUE
5 -2.0 2.0

( ) BLOCK FOR X-AXIS ( ) MINIMUM VALUE ( ) MAXIMUM VALUE
1 -2.0 2.0
PREPARE PLOTTER AND PRESS START
SET PEN ABOUT ONE INCH FROM RIGHT MARGIN

( ) PRINT INTERVAL
100.
TIME OUTPUT( ) OUTPUT( ) OUTPUT( ) OUTPUT( ) OUTPUT( )
1 5 4 8 12
RUN TERMINATED BY SWITCH 0

Fig 1.


OOSUMI
APOGEE 5164 km
PRINT INT 0.1
Time Interval
= 80.70 sec
EARTH
6370 km
5164 km