TELEDAT: An In-field Computer System for Processing Radio-telemetry Data

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Abstract: TELEDAT is an interactive BASIC computer program written for the Texas Instruments TI-74 hand-held calculator to process and store radio-telemetry location data while in the field. TELEDAT simplifies field-tracking and increases the accuracy and precision of telemetered triangulation data by: (1) providing in-field estimation of animal location and receiver-to-transmitter distance; (2) calculating error polygon size and long diagonal; (3) identifying error conditions such as azimuths that do not cross or are near-parallel; and (4) reducing the error inherent in data coding and entry. TELE-DAT uses virtually any rectangular *x-y*-coordinate system including Universal Transverse Mercator (UTM) coordinates for determining transmitter location and will store data from 1 to 50 receiver stations. TELEDAT can store up to 720 locations on a single 32K-cartridge. Use of multiple cartridges provides unlimited data storage capability. Stored data can be printed in the field or uploaded to any IBM-compatible DOS-based PC for further analysis.

Tracking animal movements using radio-telemetry triangulation can generate large amounts of data in a relatively short time. Moreover, data must often be handled several times before estimation of home range or habitat use is achieved. Several well-written home range analysis packages (DC80, HOME RANGE, McPAAL, MICRO-DIXON, TELEM/PC) are now available for the personal computer at comparatively little cost (White and Garrott 1990). Although these programs greatly simplify the otherwise tedious analysis of triangulation data once it is collected, comparatively few programs or systems have been developed to simplify the acquisition of such data in the field. Despite recent refinements in computer hardward technology, the size, price, and lack of durability under field conditions of the average laptop computer *still* largely precludes *its* use by field personnel. A laptop can be particularly unwieldy in the field because the user may also be carrying a radio receiver, antenna, and data recording equipment. While a few radio-telemetry data acquisition and analysis programs employ in-field use of portable computers (Dodge et al. 1986, Nams 1990, Biggins and Hanebury

1991), TELEDAT is the only program written exclusively for a hand-held calculator.

TELEDAT was developed as a cost-effective means for a single researcher to record and evaluate radio-location data using 2-station triangulation. Two-station triangulation is by far the most cost-effective way to obtain reasonably accurate animal locations in flat to moderately rolling terrain (Biggins and Hanebury 1991). The additional manpower and data-entry requirements for accurate triangulation from 3 stations can easily double data acquisition costs. If additional manpower is not used, the time and concomitant disturbance required for 1 person to collect >2 azimuths can significantly increase the chances of movement of the transmittered animal, thereby increasing the potential for serious error in animal location (Schmutz and White 1990, White and Garrott 1990). This can be particularly troublesome if high location accuracy is the reason researchers choose triangulation from >2 stations. Teledat can improve the accuracy of 2-station triangulation by allowing the researcher to immediately evaluate the precision of the location estimate and resample questionable locations.

My objectives are: (1) to provide the reader with an overview of TELEDAT, including informational requirements of the program, its output, and method of triangulation employed; and (2) to address system hardware capabilities, requirements, and limitations.

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Overview

Program Capabilities

TELEDAT is an interactive, menu-driven program designed to simplify radio-telemetry triangulation in the field. TELEDAT increases the accuracy and precision of animal location data by: (1) providing in-field determination of transmitter location and receiver-to-transmitter distance; (2) supplying in-field determination of error polygon size and long diameter; (3) identifying error conditions such as azimuths that do not cross or are near-parallel; and (4) reducing the error inherent in data coding and entry.

TELEDAT can store up to 50 receiver station locations and positional and error polygon information for up to 720 animal locations on a single 32K-cartridge. The ability to use multiple cartridges provides TELEDAT with unlimited data storage capability. Locational data can be printed in the field on the system's portable printer. Receiver station and transmitter location data can be easily uploaded to any IBM-compatible DOS-based PC for further analysis.

Menu Interface

TELEDAT's menu interface (Fig. 1) consists of a first-level main menu and 4 second-level sub-menus. The first choice on the main menu brings the user to the
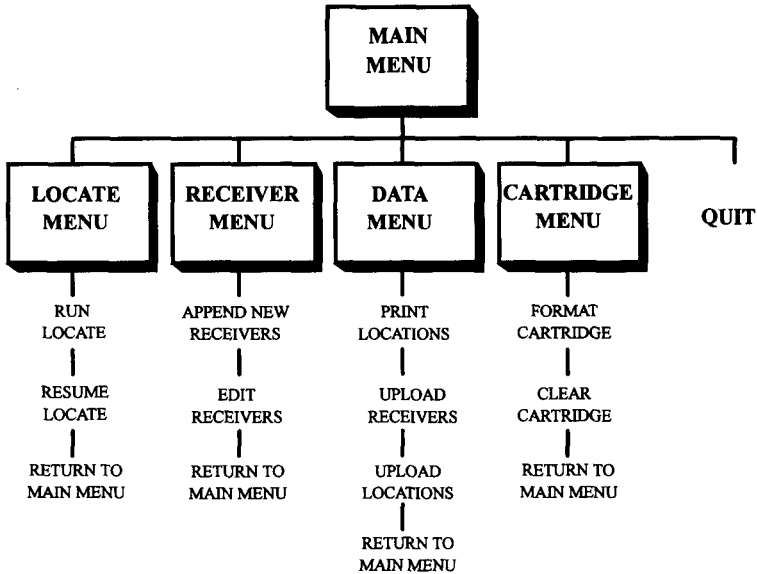
```
                          ┌──────────┐
                          │   MAIN   │
                          │   MENU   │
                          └──────────┘
     ┌─────────────┬─────────────┬─────────────┬──────────────────┐
┌──────────┐ ┌──────────┐ ┌──────────┐ ┌──────────┐
│  LOCATE  │ │ RECEIVER │ │   DATA   │ │CARTRIDGE │      QUIT
│   MENU   │ │   MENU   │ │   MENU   │ │   MENU   │
└──────────┘ └──────────┘ └──────────┘ └──────────┘

    RUN       APPEND NEW      PRINT         FORMAT
  LOCATE      RECEIVERS     LOCATIONS      CARTRIDGE

  RESUME        EDIT         UPLOAD         CLEAR
  LOCATE      RECEIVERS     RECEIVERS      CARTRIDGE

 RETURN TO    RETURN TO      UPLOAD       RETURN TO
 MAIN MENU    MAIN MENU     LOCATIONS     MAIN MENU

                           RETURN TO
                           MAIN MENU
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Figure 1.   TELEDAT's menu structure.

"LOCATE" sub-menu where the user is prompted to either begin triangulation at the first receiving station or to resume triangulation upon arrival at the second receiver location. The second choice on TELEDAT's main menu directs the user to the "RECEIVER" sub-menu which handles entry and maintenance of receiver station location and precision data. The "DATA" sub-menu is the third choice on the main menu. It allows in-field printing of location data and guides the user through the data upload process. The fourth choice on the main menu is the "CAR-TRIDGE" sub-menu which guides the user through format and erasure of the RAM cartridge. The final choice on TELEDAT's main menu, "QUIT," terminates the program.

System Input

Two pieces of information are essential before an animal's location can be determined via radio-telemetry triangulation: (1) the receiver location; and (2) some measurement of system accuracy. Receiver locations are input via the TI-74's "QWERTY" keypad and stored by TELEDAT before field triangulation begins. The "QWERTY" keypad is large enough to be used like a keyboard and is equipped with a macro feature that allows the user to input repetitive string data with a single keystroke (Quiram et al. 1986). Each receiver location is entered as an x- and y-coordinate and a standard deviation for the receiver station. This standard deviation can be derived from a prior sample of test locations (White and Garrott 1990) or estimated from prior experience when precision is not crucial. TELEDAT sequen-

tially assigns an identification number to each set of receiver location and standard deviation data so that the user needs only to enter the receiver's identification number (2 digits max.) rather than the lengthy *x*- and *y*-coordinates and standard deviation for each receiver pair.

When field triangulation begins, TELEDAT prompts the user for the number of animals in the series. A series in TELEDAT is defined as the number of animals on which the user wishes to acquire the first azimuth reading before moving to the next receiver station. The user is then prompted for the identification numbers of the 2 receiving stations to be employed in locating the current series of animals. Upon entry of the receiving station numbers the user is prompted for corrections to any of the data entered up to that point. After being prompted for the data and time, the user then enters the animal identification (character or numeric) and the first azimuth reading and is again prompted for corrections. Prompts continue until each animal in the series has had its identification and first azimuth recorded. The TI-74 can then be turned off while enroute to the second receiver station.

At the second receiver station the user is prompted for the second azimuth reading for each animal in the series. TELEDAT then calculates the animal's location, and error polygon information. The user also is prompted to enter any optional comments pertinent to the location (e.g., activity state of the transmitter, weather conditions, etc.).

System Output

The TI-74's output media consist of the 31-character LCD display, a 32-K cartridge, and the 24-column Texas Instruments (TI) PC-324 thermal printer. Upon entering the second azimuth reading for an animal, TELEDAT displays the size of the resultant 90% error polygon, the longest diagonal (Saltz and Alkon 1985), the *x*- and *y*-coordinates of the animal location, and the receiver-to-transmitter distances for each receiving station. The output to the LCD display can be suppressed for each series to save time and keystrokes when the user only desires TELEDAT's data recording features.

Output data from TELEDAT is stored in comma-delimited ASCII format on the system's 32-K cartridge. Each data record (Fig. 2) includes: date, time, receiving station numbers, animal identification, azimuth readings, 90% error polygon, largest error polygon diagonal, *x*- and *y*-coordinates of transmitter location, an indicator as to whether or not all 5 azimuths cross to form a valid error polygon, and user-entered comments. Receiving station coordinates and standard deviations are also stored on the data cartridge. TELEDAT will warn the user when the data cartridge is full and replacement or uploading is required. Once uploaded to a DOS-based PC these data can be transported easily into virtually any database, spreadsheet, or home range software for further analysis.

Location data can be printed while in the field on TI's PC-324 portable, battery-operated thermal printer. Data is printed in the same format as it is written to the 32-K cartridge (Fig. 2).

04/12/90[a],1140[b],1[c],3[d],doe#2[e],45[f],280[g],130016[h],994[i],51025[j],51025[k],X[l],active[m]
04/12/90,1140,1,3,doe#6,77,326,137189,781,53528,51199,X,
04/12/90,1140,1,3,doe#2,20,290,195149,839,50909,51625,X,mortality switch active
04/12/90,1140,1,3,buck#1,40,283,144391,912,51068,51177,X,
04/12/90,1140,1,3,buck#7,55,345,411068,1131,53447,52564,X,
04/26/90,1203,3,4,doe#2,300,190,0,0,0,0,0,weak null at stn. 4
04/26/90,1202,3,4,doe#7,350,195,0,0,53933,50882,O,
04/26/90,1202,3,4,doe#1,293,220,175233,741,52822,51000,X,
04/26/90,1202,3,4,buck#12,296,245,558995,1585,51624,51659,X,
04/26/90,1202,3,4,buck#16,323,260,323977,1077,52396,52629,X,
04/26/90,103,1,4,doe#3,88,190,373343,983,54081,50625,X,weak signal at stn. 1
04/26/90,103,1,4,doe#10,2,269,404321,963,50585,52932,X,
04/26/90,103,1,4,doe#4,80,201,334946,1122,53761,51075,X,
04/26/90,103,1,4,buck#3,5,271,413064,964,50724,53066,X,

Figure 2.   Sample output from TELEDAT: [a]date; [b]time; [c]first receiving station ID number; [d]second receiving station ID number; [e]animal identification; [f]first azimuth reading; [g]second azimuth reading; [h]90% error polygon; [i]90% error polygon long diagonal; [j]transmitter x-coordinate; [k]transmitter y-coordinate; [l]valid error polygon indication X if all 5 azimuths cross, 0 if < 5 azimuths cross; and [m]comments.

Triangulation

Location Estimation

TELEDAT's method of triangulation treats each receiver station as the center of a polar coordinate system. White and Garrott (1990) pointed out that the transformation of the polar coordinates (defined by a radial distance r from the pole and an angle θ measured in radians from an axis x) of a triangulated transmitter location into rectangular coordinates (defined by a distance x measured from a defined origin and a distance y measured from the same origin at a right angle to x) yield the following equations:

$$x_1 = r_1 \cos \theta + x_1$$
$$x_1 = r_2 \cos \theta + x_2$$
$$y_1 = r_1 \sin \theta + y_1$$
$$y_1 = r_2 \sin \theta + y_2$$

Where x_1 and y_1 = the x- and y-coordinates of the animal location, x_1 and y_1 = the x and y-coordinates of the first receiver, x_2 and y_2 = the x- and y-coordinates of the second receiver, and r_1 and r_2 = the receiver-to-transmitter distance for the first and second receivers, respectively. This system of 4 equations with 4 unknowns (x_1, y_1, r_1, r_2) can be combined by solving for r_1 and r_2 to yield 2 equations:

$$\frac{x_1 - x_1}{\cos \theta_1} = \frac{y_1 - y_1}{\sin \theta_1}$$

$$\frac{x_1 - x_2}{\cos \theta_2} = \frac{y_1 - y_2}{\sin \theta_2}$$

Employing the trigonometric identity tan θ = sin θ / cos θ, and solving for y_1 yields:

$$y_1 = \frac{(x_2 - x_1)\, \tan\theta_1\, \tan\theta_2 - y_2\, \tan\theta_1 + y_1\, \tan\theta_2}{\tan\theta_2 - \tan\theta_1} \qquad (1)$$

Replacing y_1 back into one of the original equations and solving for x_1 results in:

$$x_1 = \frac{(y_1 - y_2)}{\tan\theta_2} + x_2 \qquad (2)$$

Angle θ is measured in radians from the polar axis, however, radio-telemetry triangulation is typically done using azimuths (α). Therefore, as White and Garrott (1990) also pointed out, azimuths measured in degrees from true north must be converted to angles measured in radians from the polar axis using the following equation:

$$θ = (90 - α) * (π / 180)$$

Implementation of equations 1 and 2 in a computer algorithm poses 2 problems. The first is that tan 90° and tan 270° are ∞ and tan 180 and tan 360 are 0, therefore any azimuth corresponding to 1 of the 4 cardinal directions can result in a numeric overflow and halt the system. To remedy this, TELEDAT approximates these azimuths by subtracting 0.00001° from any azimuth corresponding to 1 of the 4 cardinal directions.

The second problem is that equations 1 and 2 cannot distinguish between a legitimate location arising from convergent azimuths or its mirror image arising from divergent azimuths crossing in the opposite direction. To remedy this, TELE-DAT checks to see that the x-coordinate of the resultant location > the x-coordinate of the receiver station if the azimuth reading is between 0 and 180 or that the x-coordinate of the resultant location < x-coordinate of the receiver station if the azimuth is between 180 and 360. TELEDAT therefore is restricted to using rectangular coordinate systems whose x-axis increases from west to east. Additionally, x- and y-units must be equivalent. This coordinate system conforms to the Universal Transverse Mercator (UTM) system (Edwards 1969).

Error Polygon Determination

Accuracy of radio-telemetry triangulation is determined by assessing the precision and bias of the location estimates. Precision measures the dispersion of a set of transmitter location estimates around their mean whereas bias measures the distance between the mean location estimate and the true location of the transmitter (Hupp and Ratti 1983). TELEDAT adds 1.96 standard deviations taken from each receiver station to either side of each azimuth to form a 95% error arc. The intersection of these 2 95% error arcs form the 90% error polygon precision estimate.

Error polygon size and shape is a function of 3 variables: (1) the angle of azimuth intersection; (2) the standard deviations of the receiving stations; and (3) the transmitter to receiver distance. All 3 of these variables must be considered simultaneously when determining the precision of radio-telemetry locations (Heezen and

Tester 1967, Springer 1979). TELEDAT first calculates the location estimate and then calculates the location of the 4 corners of the error polygon. The area of the error polygon is determined by finding the area of the 2 triangles from which it is composed.

TELEDAT determines if a valid error polygon has been formed by checking to see if the 5 different azimuth pairs that make up the error-polygon have crossed. TELEDAT reports an error condition to the user anytime < all 5 azimuth pairs cross, such as when location azimuths are near parallel or diverge.

TELEDAT does not explicitly allow input for system bias correction. Bias, however, often can be corrected by adjusting compass declination of the receiver station once the bias has been isolated (White and Garrott 1990).

Hardware

Capabilities

The TI-74 employs an 8-bit TMS 70C46 processor running at 4 MHz. It contains 8K of internal storage, is powered by 4 "AAA" batteries, weights 335g, measures 9.5 x 20.3 cm and fits in a large shirt pocket. The TI-74 will provide >50 hours of continuous operation before battery replacement is required. The TI-74's Constant Memory™ feature allows battery replacement at any time without data loss. A cartridge port allows the user to expand or customize the system for virtually any field application by adding 8k or 32k cartridge random access memory (CRAM); or erasable programmable read-only memory (EPROM) cartridges. The TI-74 also includes a rigid plastic case that protects the calculator from the elements but allows easy access to the keypad.

The PC-324 portable thermal printer is of the same approximate size and weight as the TI-74 and is powered by 4 "AA" batteries. It prints 24 characters per line at 19 characters per second on 5-cm-wide thermal paper.

Requirements

System hardware requirements for TELEDAT include the TI-74 and 32-K CRAM cartridge for storage of field data. A TI PC-interface cable is required for data uploading and a TI PC-324 printer for in-field printing.

Limitations

The TI-74's relatively slow clock speed and 8-bit processor contribute to TELEDAT's somewhat slow processing time in calculating error polygons (= 10 secs.). However, because error polygons are calculated immediately after entering the second azimuth for each animal, TELEDAT's processing time will not be a limiting factor unless the user can obtain an azimuth on any given animal in <10 secs.

The TI-74 is not equipped with an internal clock, therefore location times for each series must be entered manually.

Conclusion

TELEDAT has been used successfully to locate white-tailed deer (*Odocoileus virginianus*) involving >2,000 locations. TELEDAT offers several advantages over similar programs written for portable computers. Among these are: TELEDAT's ease of use, its concentration on field data acquisition and accuracy determination rather than home range analysis, the TI-74's manageable size and durability in the field, and the system's comparatively low cost.

Copies of the TELEDAT program and user's manual are available from the author upon request.

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