The Animal Locator: a new method for accurate and fast collection of animal locations for visible species

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Original article

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Cristian Pasquaretta, Giuseppe Bogliani, Luigi Ranghetti, Caterina Ferrari & Achaz von Hardenberg

Ranging behaviour is one of the most important aspects of the life history of many species. Spatial distributions of individuals in the wild is linked to factors such as foraging, mating, population density, availability of resources and competition. Accurate data on the spatial location of individuals over time is often difficult to collect. Here, we propose a new simple, non-invasive and economic method for collecting accurate spatial data usable for many different species of free-ranging animals. Our instrument for collecting animal locations consists of three elements: a laser range finder, a laser tilt sensor and a protractor. This instrument can obtain three-dimensional parameters of the space from a fixed point allowing the user to collect geographical locations of the animals and, in general, of any point of interest. The device we tested showed a very low average error among (1.76 ± 0.643 m) and within (1.79 ± 0.058 m) observers, and the locations we obtained were all within the 95% probability of the tolerance intervals for the 20 positions which we measured repeatedly with a Global Position System for each of 10 different test locations. We tested a range of different distances to the target points (from 20 to 222 m), and we propose formulas to calculate precision of the instrument inside this interval. Precision of estimated locations was between 0.32 to 3.55 m from the real location and it was slightly related to distance of the target point (r = 0.38, P = 0.054). As an example of its practical application, we present data on the use of the instrument within the framework of a study on a population of free-ranging individually tagged alpine marmots *Marmota marmota*.

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The spatial location of individually recognisable animals is possibly one of the main, and sometimes, the only kind of data researchers collect in studies on the ecology of wildlife species. Data collected over time with the appropriate methods allow the researcher to estimate many parameters of interest to wildlife biologists such as: home-range size (Salsbury & Armitage 1994, Börger et al. 2008), movement routes (Lipp et al. 2004), nearest neighbour distance (Buskirk 2004), starting and flight initiation distance (Blumstein 2003, Cooper & Frederick 2007). Combined with other information, these parameters are essential in studies on habitat selection (Manly et al. 2002), persistence of a population (Ozgul et al. 2006), territorial behaviour (Manno & Dobson 2008, Leuchtenberger & Mourão 2009), dispersal (Beier & Noss 1998), migration (Meyburg et al. 1996), energetic expenditure and requirements (Carbone et al. 2005) or anti-predatory behaviour (Fernandez-Juricic et al. 2004).

According to the peculiarities of the studied species, several methods are used to collect locations of individually recognisable free-ranging animals over time, including radio-tracking (White & Garrot 1990), trapping grids (MacKenzie et al. 2006) and harmonic radar (Mascanzoni & Wallin 1986). Repeated animal handling and occasionally surgical operations (e.g. Salsbury & Armitage 1994) are required in these methods, and this may potentially have a negative impact on the well-being of the studied subjects and ultimately also on the reliability of the results (Murray & Fuller 2000). Furthermore, radio-tracking methods often entail considerable measurement errors both when based on VHF radio-transmitters (Rouys et al. 2001) and more recently introduced GPS telemetry systems (Hurford 2009). For example, Rouys et al. (2001) show that radio-tracking seems to overestimate the distance walked by European bison *Bison bonasus* when the animal walked from 0 to 25 m while the true walking distance between two radio-locations was < 10 m.

A simple and non-invasive alternative is the direct visual observation of tagged individuals. This method, while it is unsuitable or of very limited use for many species with poor detectability or with very large ranges, has the advantage of permitting the collection of behavioural data along with the location of the observed animal. Furthermore, it appears to be the favoured method for visible species with limited home ranges, which can easily be monitored from one or few observation points (Martin & Bateson 1993). Species falling into this category potentially include most of the terrestrial squirrels (subfamily Xerinae), including 14 species of marmots *Marmota* spp., five species of prairie dogs *Cynomys* spp., 25 species of chipmunks *Tamias* spp. and 42 species of ground squirrels of the genus *Spermophilus*. Other species which have been or could be studied following this methodology include harbour seals *Phoca vitulina* during lactation (Thompson et al. 1994), lekking sage grouses *Centrocercus urophasianus* (Gibson & Bradbury 1985) and small lizards *Lacerta* spp. (Eason & Stamps 1992). An objective method to accurately estimate the location of an observed animal from a distance would be of great interest for behavioural ecologists and wildlife biologists interested in the space use of tagged or naturally recognisable animals. Obviously, the capture and marking of animals is invasive in itself, but the collection of repeatable and accurate measures from fixed observation points allows the animals to

get used to the researchers, reducing the potential disturbance arising from their presence (Crofoot et al. 2010).

Different methods attempt to provide locations as accurate as possible from a distant observation point. For example, Lacey & Wieczorek (2001) and Manno & Dobson (2008) obtained the location of visually observed ground squirrels by dividing their study area in non-overlapping sections with boundaries determined by the shape of the meadow, and then record the locations of each visible animal to the nearest metre on a Cartesian grid. Maher (2009) noted woodchuck *Marmota monax* locations with respect to the nearest burrow for which he had previously obtained GPS measures. These methods all rely somehow on subjective estimations of distances or positions relative to landmarks, and therefore, they are potentially prone to error. Furthermore, the accuracy and reliability of these methods are often difficult to estimate. Fehmi & Laca (2001) introduced a computerised instrument to collect animal locations in the wild from an observation point. They proposed to use a survey theodolite mounted on a tripod and connected to a laptop computer. Their instrument appears to be accurate, but could potentially suffer from problems due to meteorological variability and energy requirements in particular because of the presence of a computer in the field area. Despite the optical characteristics of a survey theodolite which are subject to reflectance problems, the authors claim that it is useful up to a distance of 300 m. Moreover, the possibilities of recharging batteries may be very limited, and the distances a researcher has to walk to reach an observation site may be far from the base camp, especially in remote conditions.

Based on the original idea of Fehmi & Laca (2001), we here propose the use of a simpler and relatively cheap instrument, hereafter called the 'Animal Locator', designed for rapid collection of accurate locations of visually observed wild animals. We repeatedly estimated the location of previously geo-referenced target points to validate the accuracy and to estimate the precision of the Animal Locator. To assess location precision, we propose formulas depending both on the precision of the equipment on which it is based as well as the distance and the tilt of the target in respect to the observer. We exemplify its practical use on a population of free-ranging individually tagged alpine marmots *Marmota marmota* presenting results on individual home-range size estimated for the summer season 2008.

Material and methods

Study area and species

We developed the method in the Gran Paradiso National Park (GPNP) located in the northwestern Italian Alps (45°34'N, 7°11'E). The Aninmal Locator was tested in the study area of Orvieille at 2,165 m a.s.l. where about 70 alpine marmots are individually tagged each year and have been monitored since 2007. Our study area was above the tree line and was characterised by low vegetation and few bushes. Alpine marmots are social, ground-dwelling rodents inhabiting alpine meadows and living in family groups of up to 20 individuals (Arnold & Dittami 1997). We live-trapped alpine marmots in 2008 using 19 Tomahawk traps ($150 \times 30 \times 30$ cm). Animals were then transferred in a handling bag. Further manipulations of the animals were conducted following the guidelines for the capture, handling and care of mammals as approved by the American Society of Mammalogists (Gannon & Sikes 2007). We marked the animals using a unique microchip transponder under the skin (Animal Coder, Bayer), plastic coloured ear tags (Minirototag 5 cm, Ghislandi, Italy) with different colour combinations and fur dye for visual recognition at a distance. We assigned sex and age classes based on anogenital distance and weight measures, respectively (Zelenka 1965). We were able to categorise individuals in three age classes: adult (> 2 years of age), subadult (1-2 years old) and young (< 1 year old).

Definition of the measures of interest

The measures we were interested in were the absolute east and north geographical coordinates of the observed animals. The relative east and north coordinates of a target P_i observed from a fixed observation point P_{obs} in a tridimensional space (e.g. the mountaneous orography of our study area) can be obtained trigonometrically knowing the distance ρ, tilt angle λ and orientation α from P_{obs} to P_i using the following formulas:

$$East = (\rho_i \times \cos(\lambda_i) \times \sin(\alpha_i)) \qquad (1A)$$

$$North = (\rho_i \times \cos(\lambda_i) \times \cos(\alpha_i)) \qquad (1B).$$

These relative coordinates can thus be added to the absolute UTM coordinates of P_{obs}. These were previously estimated using a GPS unit (Trimble GeoExplorer handheld GPS), retaking the coordinates 20 times in different days over the season in order to randomise the effect of the daily satellites unevenness (Johnson & Barton 2004) and to increase the accuracy of the location. The average of all 20 longitudinal and latitudinal measurements was thus used as the most accurate estimate of P_{obs}. The absolute orientation of the target point can be assessed following the method described in Appendix I.

The Animal Locator instrument

The Animal Locator is made of three different elements: a laser range finder that measures the distance from the observer to a target, a laser tilt sensor and a protractor to measure the angle in relation to a fixed point. We used a Swarovski Range Finder 8×30 (Swarovski optik KG, Absam, Austria) with an accuracy of 1 m and maximum distance of 500 m, a Leica Disto A8 (Leica Microsystem Srl, Milan, Italy) tilt sensor with an accuracy of 0.05°, and a simple plastic protractor glued on a rigid surface in order to be able to measure the horizontal angle. The three elements are easily combined in a single instrument mounted on a tripod as seen in Figure 1. A gas bubble level ensures that the protractor is horizontal in relation to the ground. A simple protractor, pointed at a fixed zero point (Fig. 2), was preferred over the use of a compass because, after preliminary trials, the latter appeared to be too variable because of the instability of the magnetic domain. The zero of the protractor is directed towards a fixed zero point landmark. In our marmot study, a well recognisable rock in our study area, located at 68 m from the observation point, was

Figure 1. The Animal Locator consisting of the range finder, the tilt sensor and the protractor are combined on the same tripod. A gas bubble level ensures the protractor is horizontal in respect to the ground.
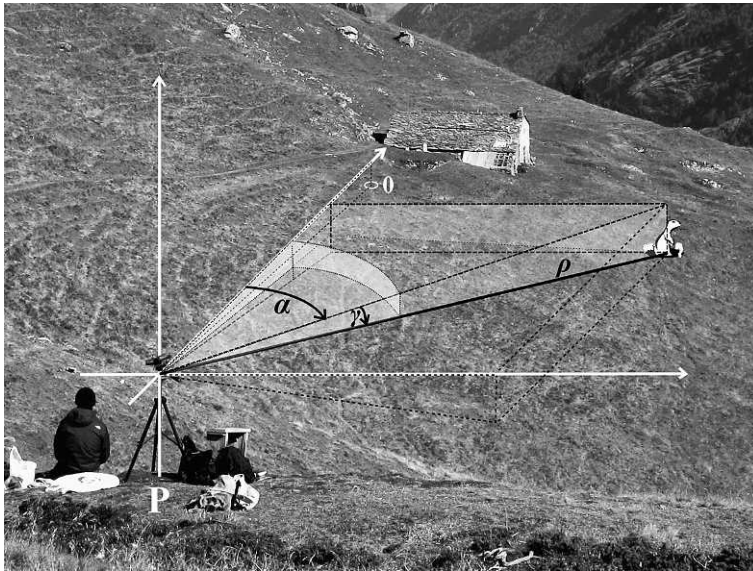
Figure 2. Schematic representation of the angles and the distances needed in order to obtain the position of the observed subject. The instrument is set on observational point P_{obs}, α_i is the orientation of the animal in respect to the zero point, γ_i is the tilt and ρ_i is the distance from the instrument to the observed subject.

chosen as a permanent zero point. The geographical coordinates of the zero point were established with a GPS unit in the same way described above to estimate the coordinates of observation point P_{obs}. Before starting a measuring session, the Animal Locator was set on the tripod at a standard height of 1 m above the ground and the bubble level was checked to make sure that the protractor at the base of the instrument was horizontal. Once the Animal Locator was set, we used the viewfinder of the range finder to point the target and thus to get measures of ρ, λ and α.

Differences among observers

We repeatedly collected locations of 10 target points, previously geo-referenced with a GPS, by having seven different naive observers doing the measurements three times each. Each of the seven observers independently measured the coordinates of the 10 landmarks during the same day in spring 2011. We calculated the average value of the obtained variance among the measurements from mixed effects models built for each of the 10 targets in order to eliminate the effect of variance due to different locations of the target points. Each model has the intercept fitted together with observer identity as a random effect (Nakagawa & Schielzeth 2010). The proportion of total variance, due to the differences among the observers, was calculated following Sokal & Rohlf (1995)'s formula by extracting variances from the summary function of the 'nlme' package in R (Pinheiro et al. 2010) for the linear mixed effect models (Nakagawa & Schielzeth 2010).

Comparison of coordinates estimated with the Animal Locator and GPS estimated coordinates

In order to test whether the Animal Locator is able to estimate coordinates of a target point comparable with those estimated with a GPS unit, we distributed 10 random target points in our study area. The points were geo-referenced with a GPS unit in the same way as described above to estimate the coordinates of observation point P_{obs}. We thus checked if the east and north UTM coordinates, obtained by the Animal Locator for each of the 10 previously geo-referenced target points, were within the 95% probability of the tolerance region (Vangel 2005) of 50% of the 20 repeated GPS measurements used for geo-referencing the target points. We chose to calculate the tolerance region using 50% of our GPS repeated measurements rather than 100% of the points, because we were interested in testing if our Animal Locator was also accurate with a smaller range of tolerance. Tolerance regions were calculated by Monte Carlo simulations using the package 'tolerance' (Young 2010) for the statistical environment R 2.11.1 (R Development Core Team 2010). Monte Carlo simulation appears to be the best method to calculate tolerance regions having a multivariate distribution (Krishnamoorthy & Mondal 2006). The simulations are shown in Figure 3.

To evaluate how the precision of the Animal Locator compared with our GPS's precision is, we compared the standard deviation of our 20 repetitions for each point expressed in the original units with the absolute value of the differences between the coordinates estimated with the Animal Locator and

Figure 3. The 95% tolerance regions for six repetitions by seven different observers for each point (1:10) are shown. The asterisk point and the curved line are the mean of the 20 measurements obtained using the GPS and their tolerance regions, respectively. Black points are the original data which we collected using a GPS unit. The numbered points represent the sum of the 21 repetitions collected for each point using the Animal Locator that fall on the same position.
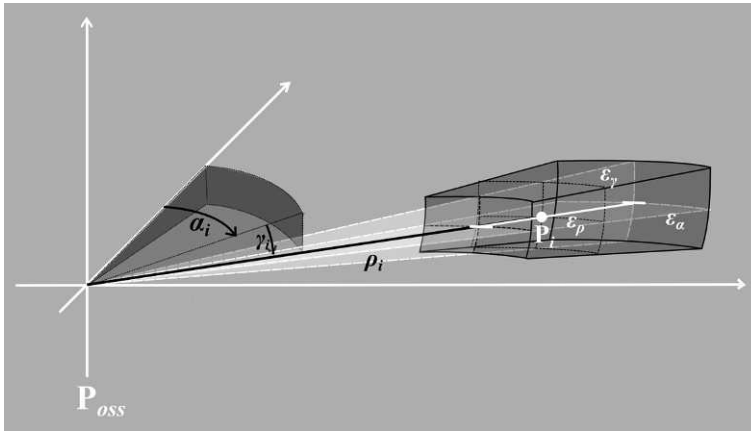

NORTH UTM COORDINATES

EAST UTM COORDINATES

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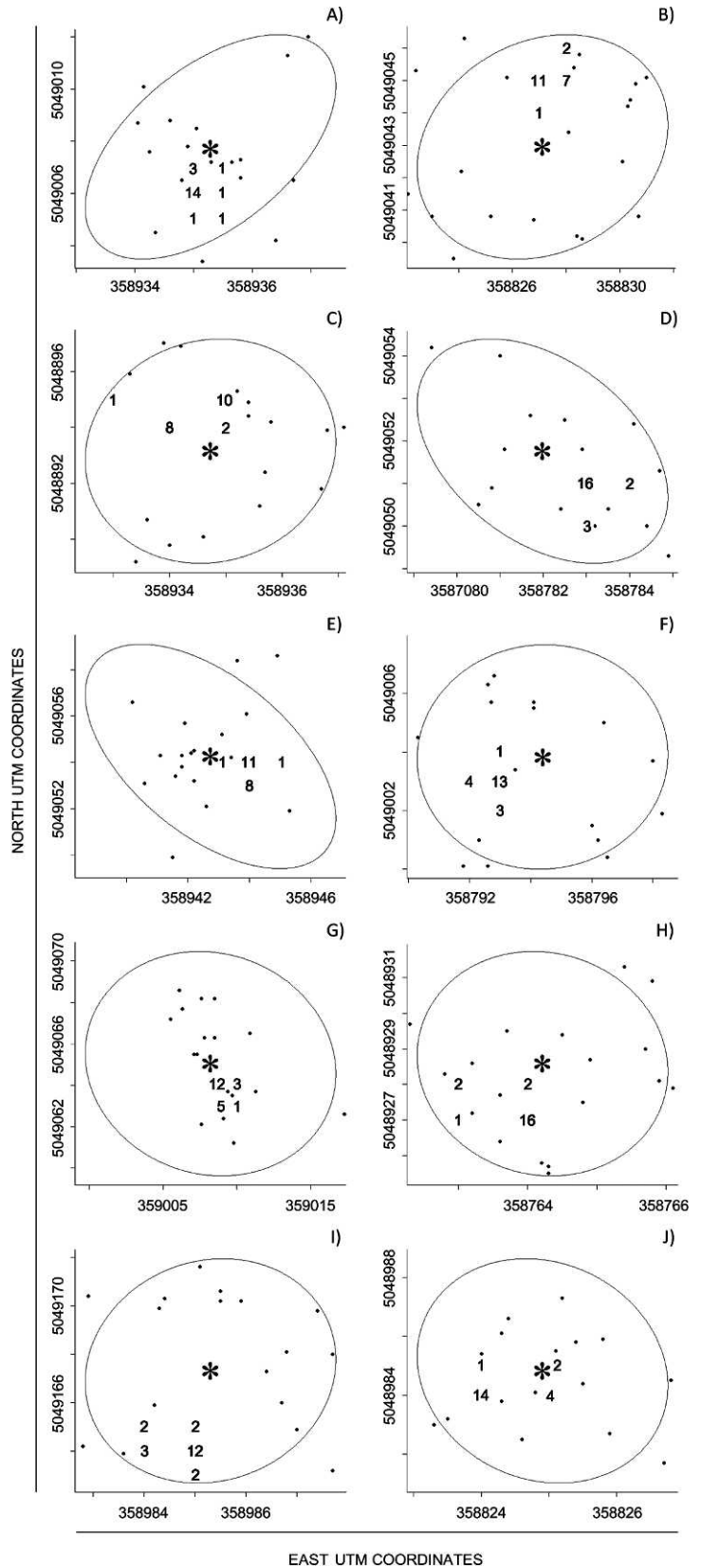
Figure 4. Schematic representation of the errors ε_ρ, ε_α and ε_γ. Errors for each single measure are shown in white (i.e. white line for ε_ρ and two circular sectors for ε_α and ε_γ). Polygon bearing out from the combination of the error parameters is shown with a solid line.

with a GPS unit. For each target point, we thus verified whether these measures were lower than the standard deviation of the 20 measures collected with the GPS unit.

Error area around the estimated locations and estimation of precision

Each estimated location is connected with an error that can be represented by a polygon around the estimated locations (White & Garrot 1990). The position of each point P_i is obtained from measurements of the three spherical coordinates (ρ_i, α_i, γ_i), as described above. It follows that the measurement error of each point depends on the specific accuracy of the equipment that forms the Animal Locator. Figure 4 shows the three instrument errors: $\varepsilon_\rho =$ distance error, $\varepsilon_\alpha =$ orientation error and $\varepsilon_\gamma =$ tilt error. The neighbourhood of such errors is a portion of the sphere, highlighted in black in Figure 4, which for simplicity can be approximated to a parallelepiped.

The measures of the solid are $\Delta\rho_i$, $\Delta\alpha_i$ and $\Delta\gamma_i$, and they depend on instrument errors (Fig. 5A) following the formulas:

$$\Delta\rho_i = \varepsilon_\rho \qquad (2A)$$

$$\Delta\alpha_i = 2\rho_i \times \cos\left(\frac{\varepsilon_\alpha}{2}\right) \qquad (2B)$$

$$\Delta\gamma_i = 2\rho_i \times \cos\left(\frac{\varepsilon_\gamma}{2}\right) \qquad (2C).$$

Figure 5B shows the projection of the solid on the XY plane. Consequently, the figure error is a rectangle of sides $\Delta\alpha_i$ having the maximum distance from the real position $d_i = \sqrt{\Delta\rho^2_{\perp i} + \Delta\alpha_i^2}$. Measures of the solid can be used to calculate both the four points of the

rectangle ($P1_i$, $P2_i$, $P3_i$ and $P4_i$), centring the figure on $P_i(X_{P_i}, Y_{P_i})$ and turning it based on the orientation α_i. The maximum error distance d_i, represents the precision of the Animal Locator, following the formulas in Appendix II. d_i is a function of ρ_i and γ_i and it depends on the parameters ε_ρ, ε_α and ε_γ. In order to define these parameters, we used the sensibility of the used equipments when it was bigger than their precision. Otherwise, we estimated precision based on a standard deviation for all the 210 measures collected (i.e. three repetitions for seven observers for 10 target points). The range finder and the tilt sensor we used had electronic reading, and therefore, their sensibility is equal to the minimum measurable distance and tilt: 1 m and 0.05°, respectively. Instead, the protractor has optical reading and we used double the distance between two consecutive notches equal to 1.8°, because we used a protractor of 400° instead of 360°.

Variation in accuracy and precision with distance of measurement

We tested the accuracy of the Animal Locator in order to check whether the error between estimation and real location (Euclidian distance) increased with the distance of the targets using a linear regression. We extracted and averaged standard error for east and north coordinates from 10 linear mixed effect models built for each target point using three observations for each observer. After testing for normality of the variable using the Shapiro test, we used linear regression to invesitgate the relationships between the mean distance for each point and the standard error for inclination and orientation. We used a Breusch-Pagan test to assess heteroscedasticity with the distance of the variables involved in the linear regressions.

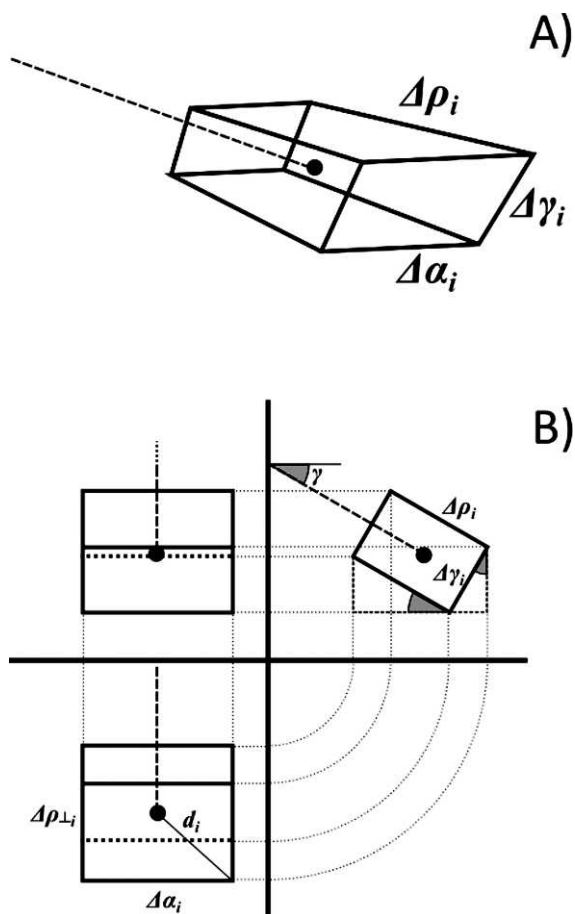To verify if precision (i.e. d_i) decreased as distance

Figure 5. Polygon error projection on the XY plane. A) the solid deriving from the combination of the errors of the three parameters: distance, tilt and orientation. B) the projection on the XY plane of the polygon. Error area for each point P_i is a rectangle of sides and $\Delta\rho_{\perp i} = \Delta\rho_i \times \cos(\gamma_i) + \Delta\gamma_i \times \sin(\gamma_i)$, in which the higher distance from the centre is represented by $d_i = \sqrt{\Delta\rho_{\perp i}^2 + \Delta\alpha_i^2}$. Polygon shown in B) can be calculated following the R command in Appendix II at the section # Polygon calculation.

of measurement increased, we tested the correlation between standard deviation of the measured distances and the measured values for the tilt (electronic device) with Euclidian distance between P_i and P_{obs}. We used the mean of the 10 standard deviations for protractor values (0.4°), because we hypothesised that there would be no relationship between standard deviation and real value for this measure. We generated regular sequences of the two parameters ρ_i and γ_i based on the same errors ε_ρ, ε_α and ε_γ of the used equipment in order to estimate their influence on d_i and evaluate the slope of the relationship between parameter and precision while accounting for a small data set (Appendix II: R command section). We fitted two linear regression models to

check whether there were significant effects of ρ_i and γ_i on the precision. We used R version 2.11.1 (R Development Core Team 2010) for all statistical analyses.

Field methods used for the applied example on alpine marmots

We used the Animal Locator to collect locations and estimate age and sex specific home ranges of alpine marmots. We applied a modified scan sampling method (Martin & Bateson 1993) collecting data on each individual belonging to the same family group for one hour, with a minimum interval of five minutes between consequent fixes for the same individual in order to avoid autocorrelation (De Solla et al. 1999). We performed 155 hours of observations between 11 June and 19 September in 2008. We calculated home-range size using the fixed kernel method with least-squares cross-validation (Worton 1989) using a fixed smoothing parameter h. In order to estimate home ranges, we collected at least 30 locations for each animal (Seaman et al. 1999). Finally, we used a linear mixed effect model (using the R package 'nlme'; Pinhero et al. 2010) to explain individual home-range size using age, sex and home-range size of the family group as fixed effects and identity of the individual as a random effect.

Results

Variance due to the differences among the observers explained only 8.8% of the total variance. The average error in metres between and within observers was 1.76 ± 0.643 m and 1.79 ± 0.058 m, respectively.

All the coordinates which we obtained with the Animal Locator for target objects were inside the 95% tolerance intervals of the reference coordinates (Table 1), and the position in the space of the coordinates estimated with the Animal Locator were within the tolerance regions. The absolute value of the differences between the reference coordinate and the coordinates obtained with the Animal Locator were < 1 value of standard deviation for each target point (see Table 1).

Tilt, orientation and Euclidian distance between estimation and real position were normally distributed (W = 0.9452, P = 0.610; W = 0.9492, P = 0.658; W = 0.9431, P = 0.592). The Breusch-Pagan test for heteroscedasticity showed an absence of increasing variance with the mean for the three regressions (BP = 0.123, df = 1, P = 0.732;

Table 1. North and east values for each point collected with the Animal Locator. The 'In-Out' column contains the results of the comparison between these values and the 95% tolerance intervals (TI) of the 50% proportion of the population derived from reference coordinates (RC) calculated using GPS. The column OC is the mean value for the coordinates obtained by all the observers using the Animal Locator. The column | OC - Mean(RC) | is the absolute value of the differences and SD is the standard deviation from the mean of the 20 GPS measurements. The Lower-Higher column gives a comparison between the | OC - Mean(RC) | and SD columns to show how the value of the first column is always smaller than the latter one.

Point	OC (m)	95% TI of RC (m)		In-Out	| OC - Mean(RC) |	SD	Lower - Higher
1 North	5049006	5049005	5049010	In	1.69	2.82	Lower
1 East	358936.1	358933.9	358939.2	In	0.44	2.79	Lower
2 North	5048895	5048891	5048896	In	1.71	2.64	Lower
2 East	358933.3	358933	358936.4	In	1.39	1.80	Lower
3 North	5049053	5049051	5049057	In	0.83	3.10	Lower
3 East	358944	358940.3	358945.2	In	1.26	2.60	Lower
4 North	5049064	5049062	5049068	In	1.19	3.51	Lower
4 East	359009.4	359002.3	359016.6	In	0.04	7.53	Lower
5 North	5049164	5049164	5049170	In	3.10	3.19	Lower
5 East	358984.7	358983.6	358986.9	In	0.57	1.73	Lower
6 North	5049045	5049041	5049045	In	2.15	2.32	Lower
6 East	358827.5	358824.2	358830	In	0.33	3.05	Lower
7 North	5049051	5049050	5049054	In	1.27	1.98	Lower
7 East	358783.1	358779.9	358783.9	In	1.27	2.10	Lower
8 North	5049003	5049001	5049006	In	0.83	2.52	Lower
8 East	358792.6	358791	358797.1	In	1.44	3.24	Lower
9 North	5048927	5048927	5048931	In	1.25	2.02	Lower
9 East	358763.9	358763.1	358765.3	In	0.36	1.16	Lower
10 North	5048984	5048982	5048987	In	0.68	2.47	Lower
10 East	358824.4	358823.8	358826.0	In	0.52	1.20	Lower

BP = 0.196, df = 1, P = 0.664; BP = 0.273, df = 1, P = 0.601). The linear regressions showed non-significant relationships between distance and standard error of the tilt (r = 0.03, P = 0.633), distance and standard error of the orientation (r = 0.09, P = 0.388), but there was a strong tendency for the relationship between distance and Euclidian distance (r = 0.38, P = 0.054; Fig. 6).

Average standard errors of coordinates obtained with the Animal Locator were 0.12 and 0.11 m for east and north, respectively. We found no significant correlation between estimation of the precision d_i and distance (r = 0.10, P = 0.372) or between d_i and tilt values (r = 0.08, P = 0.432). The arithmetic mean of the 10 standard deviations for distance and tilt were 0.4 m and 0.2°, respectively. Estimated precision d_i for all the 210 positions collected (three repetitions for seven observers for 10 target points) ranged from 0.32 to 3.55 m, and this last value was related to the farthest distance tested (i.e. 222 m). Simple linear regression models applied to the generated data set showed a significant positive effect of distance on precision (r = 0.99, P < 0.001), but no effect of tilt (r = 0.001, P = 0.721). The 95% confidence intervals of the slope for the generated data set were: 0.014-0.015, while for the real data set they were: -0.001-0.013.

We tested the use of the Animal Locator in an ongoing study on individually tagged alpine marmots in the Italian Alps. We collected 4,822 fixes for 68 different marked marmots in 2008. The maximum number of locations an observer was able to collect in
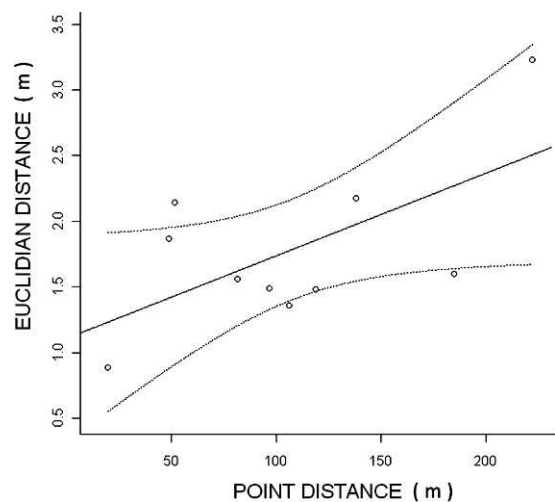

Figure 6. Scatterplot representing the Euclidian distance between estimated location and mean of the 20 GPS measures and distance of the target points. Best fitted regression line and its 95% confidence interval are represented.

a single day during a study on the activity budget of marmots was 120. Mean home-range size in hectares was: adult males (1.106 $\pm$ 0.566), subadult males (0.721 $\pm$ 0.278), young males (0.570 $\pm$ 0.416), adult females (0.889 $\pm$ 0.438), subadult females (0.692 $\pm$ 0.343) and young females (0.719 $\pm$ 0.204). The linear mixed effect model, that took the home-range size of the family group into account ($F_{9,4803} = 9.49$, P = 0.013), suggested both a significant influence of age ($F_{3,4803} = 17.98$, P < 0.0001) and sex ($F_{2,4803} = 11.62$, P = 0.001) on individual home-range size.

Discussion

Usability of the Animal Locator

The Animal Locator introduced in this paper shows a high accuracy in collecting spatial geographical data of objects located at a distance from the observer. Following Nakagawa & Schielzeth (2010), the fact that proportion of variance due to differences among observers is low can be explained by two reasons: a high within-individual variation or a low between-individual variation. Considering our data set, we can say that observer identity has a very small influence on the total variance of the location, and this is particularly important for long-term behavioural studies, which involve many field researchers and assistants collecting data during different years. The very low average distance error between (1.76 $\pm$ 0.643 m) and within (1.79 $\pm$ 0.058 m) observers from the real position, suggests that the low proportion of variance due to observers could be derived from the small variation occurring between individuals, and it underlines the accuracy of our Animal Locator that can be operated by different researchers within the same study.

The Animal Locator can easily be used to achieve geographical positions during studies of many different animal species. However, its use is possibly limited to open sites with good visibility. Preliminary observations should also be conducted to assess the impact of different degrees of vegetation cover on the detectability of the animals. By using a laser range finder, the Animal Locator avoids the reflectance problems of a theodolite based device (Fehmi & Laca 2001), which needs a reflectance surface to estimate the distance to a target point. The proposed Animal Locator can be used during the whole day in the field allowing the observer to collect an appropriate amount of data for ethological studies (Opiang 2009), and it has no animal-handling requirements.

Another advantage is the possibility to collect data according to a standardised sampling design (e.g. one location every five minutes), while GPS may miss data because of location failure. One further advantage of our method is that it reduces the problem described in Hurford 2009: the spurious effect of GPS that could lead to systematic errors in animal moving or stationary behaviour when collecting animal positions < 20 m from each other, because the highest error we found was equal to 3.55 m. Collecting absolute coordinates of a target point is not always essential. Many other methods to obtain measures of interest such as simple distance between points (Blumstein 2006, Møller 2008) or the relative position of the animal in the field are available (Somers & Nel 2004). However, few of them provide an easy and fast way of collecting precise and accurate data while accounting for estimation errors.

Accuracy and potential biases

Standard deviation of the 20 repeated GPS localisations acquired that each of the 10 tested reference points were higher than the differences between the coordinates obtained from the Animal Locator and the mean of the 20 measures. All measures obtained by the Animal Locator were inside the tolerance regions using 50% of the repeated measures at the 95% level of probability. Our Animal Locator thus provided a good estimation of the locations compared to those we could obtain by using GPS measurements with a gain in precision of about 65% (see Table 1). Given the low power of our empirical test, we found that Euclidian distance between estimation and real position was somewhat related to the distance of the target points from the observer; with an observation distance ranging from 19.78 to 222.24 m, the expected error increased from 1.1 to 2.6 m (see Fig. 6). Because estimating locations at a higher distance than the range we tested may increase the error between estimated locations and real position further, we advice not to estimate locations at a distance > 200 m with a comparable configuration to the one presented here. The small average standard error of the mean for each location (0.12 and 0.11 m) shows that very precise measures can be obtained with our Animal Locator. Equipment used to build the Animal Locator have a given sensibility that we used to obtain error parameters used to build an error area around our punctual estimates of the coordinates (see White & Garrot 1990). The marginal error of the angle may nevertheless be reduced using a digital protractor.

In agreement with the empirical data, our generated data showed that maximum error distance d_i, a function of ρ_i and γ_i, was influenced more by the distance of the target points than by the tilt sensor within the range we tested. The strong linear relation between precision and distances to the target point, and the low influence of tilt on the precision, lead us to suggest the possibility of fixing the tilt at the median value derived from simulations (tilt = 0.12 radian) in order to simplify the formulas and still obtain acceptable error estimations without needing to use a tilt device. The formulas we propose can be applied using the R commands in Appendix II. The maximum distance from the observer at which we tested the Animal Locator was of 222 m, and we recommend to run preliminary tests on the influence of distance on the measurement error in case the location of animals at longer distances have to be estimated.

Applied example and conclusions

Variability in collecting animal location data depends on biology and visibility of the animals, but by using our Animal Locator, we were able to collect a huge number of locations on free-ranging alpine marmots, during the whole season. We showed how data generated by the Animal Locator could be used to calculate age and sex specific home-range sizes in alpine marmots. Home-range size appears to be strongly influenced by age and sex with adult males having the largest home ranges compared to females and younger age classes. Our results on this species are in agreement with the ones described by Perrin et al. (1993), where the range for the territory size of alpine marmot was between 0.9 and 2.8 ha. Our results on the sex and age differences in home range also support the results of Bel et al. (1995), who showed how individuals of different sex and age classes marked different home-range areas. In their study, they showed that males marked more in overlap zones than females, which usually were found closer to the centre area of the family home range. They also found differences between adults and younger animals in the location of scent markings.

Researchers need techniques that allow fast and precise measurements of animal positions such as the locations of all the individuals within a group (Fehmi & Laca 2001). With a price of 1,000 € for the whole equipment, our system provides an affordable and accurate method for fast and precise collection of animal locations in a repeatable and comparable way. The total weight of the whole instrument is < 3.5 kg, and it is thus also widely usable in field settings reachable only by foot (e.g. mountain sites). In comparison, the average weight of a survey theodolite, which could be used for the same purpose, is 11 kg.

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Appendices

Appendix I. Zero point orientation

In order to get the real orientation of the zero point, and thus of the seven tested points, we used 25 toponyms $X_{(1:25)}$ on a cartographic map (1:10,000) and a GIS software applying the following procedure:

$X_j(N_j, E_j)$ is one of the n known points and $P(N_p, E_p)$ is a generic fixed observation point. We calculated the real orientation of X_j by using these formulas:

$$\alpha_j = \text{Arctan}((E_j - E_p)/(N_j - N_p)) \quad (1),$$

where α_j is the orientation to the north of the point X_j, E is the east coordinate and N is the north coordinate.

$$A_r = A_j - A_{zero} \quad (2),$$

where A_{zero} is the value of the angle of X_j obtained using the fixed zero point. A_r is the real orientation of the zero point to be added to each angle calculated from all of the seven points. The values in formula (2) contain bias: A_{zero} has 1° of bias because of the sensibility of the protractor. A_j has bias due to a sum of errors (ϵ): cartographic map error ($\epsilon_m = 25$ m) and the error (ϵ_{dist}) due to the distance (dist) between the observation point and the toponomycs n points, since while dist increases ϵ_{dist} decreases

$$\epsilon_{dist} = 2\,\text{Arc tan}(\epsilon_m/2\text{dist}) \quad (3).$$

If we force ϵ to be equal to or less than the error of A_{zero} and to be more precise $\epsilon = 1$, the minimum distance at which we have to choose the points is:

$$\text{dist} = 1,432\text{ m}.$$

For this reason, the 25 toponomyc points we used were from 2,700 to 36,000 m away.

Appendix II. Formulas for polygon and error calculation

We used following formulas to calculate the four points of the rectangle in Figure 5B:

$$P1_i\left(X_{P_i} + \frac{\Delta\rho_{\perp i}}{2}\times\sin(\alpha_i) + \frac{\Delta\alpha_i}{2}\times\cos(\alpha_i), Y_{P_i} + \frac{\Delta\rho_{\perp i}}{2}\times\cos(\alpha_i) - \frac{\Delta\alpha_i}{2}\times\sin(\alpha_i)\right) \quad (4A),$$

$$P2_i\left(X_{P_i} - \frac{\Delta\rho_{\perp i}}{2}\times\sin(\alpha_i) + \frac{\Delta\alpha_i}{2}\times\cos(\alpha_i), Y_{P_i} - \frac{\Delta\rho_{\perp i}}{2}\times\cos(\alpha_i) - \frac{\Delta\alpha_i}{2}\times\sin(\alpha_i)\right) \quad (4B),$$

$$P3_i\left(X_{P_i} - \frac{\Delta\rho_{\perp i}}{2} \times \sin(\alpha_i) - \frac{\Delta\alpha_i}{2} \times \cos(\alpha_i), Y_{P_i} - \frac{\Delta\rho_{\perp i}}{2} \times \cos(\alpha_i) + \frac{\Delta\alpha_i}{2} \times \sin(\alpha_i)\right) \quad (4C),$$

$$P4_i\left(X_{P_i} + \frac{\Delta\rho_{\perp i}}{2} \times \sin(\alpha_i) - \frac{\Delta\alpha_i}{2} \times \cos(\alpha_i), Y_{P_i} + \frac{\Delta\rho_{\perp i}}{2} \times \cos(\alpha_i) + \frac{\Delta\alpha_i}{2} \times \sin(\alpha_i)\right) \quad (4D),$$

while the maximum distance d_i was calculated as:

$$d_i = \sqrt{\left(\varepsilon_\rho \times \cos(\gamma_i) + 2\rho_i \times \cos\left(\frac{\varepsilon_\gamma}{2}\right) \times \sin(\gamma_i)\right)^2 + \left(2\rho_i \times \cos\left(\frac{\varepsilon_\alpha}{2}\right)\right)^2} \quad (5).$$

R command used for:

```
# Polygon calculation:
polygon <- function(X,Y,dist,tilt,or,dist_err=1,
    tilt_err=0.20/(360/(2*pi)),or_err=1.8/(360/
    (2*pi))) {
base <- 2*dist*sin(or_err/2)
high <- abs(dist_err*cos(tilt))+abs(2*dist*sin
    (tilt_err/2)*sin(tilt))
XP = X+dist*cos(tilt)*sin(or)
YP = Y+dist*cos(tilt)*sin(or)
X1 = XP+high/2*sin(or)+base/2*cos(or)
Y1 = YP+high/2*cos(or)-base/2*sin(or)
X2 = XP-high/2*sin(or)+base/2*cos(or)
Y2 = YP-high/2*cos(or)-base/2*sin(or)
X3 = XP-high/2*sin(or)-base/2*cos(or)
Y3 = YP-high/2*cos(or)+base/2*sin(or)
X4 = XP+high/2*sin(or)-base/2*cos(or)
Y4 = YP+high/2*cos(or)+base/2*sin(or)
data.frame("P"=c(XP,YP),"P1"=c(X1,Y1),
    "P2"=c(X2,Y2),"P3"=c(X3,Y3),
    "P4"=c(X4,Y4), row.names=c("X","Y") ) }

# maximum distance calculation :
or_err_degree = 2*360/400
dist_err = 1
tilt_err_degree = 0.20
or_err <- or_err_degree / (360/(2*pi))
tilt_err <- tilt_err_degree / (360/(2*pi))

D_dist <- dist_err
D_or <- function(dist) 2*dist*sin(or_err/2)
D_tilt <- function(dist) 2*dist*sin(tilt_err/2)
D_dist_perp <- function(dist,tilt)
    abs(D_dist*cos(tilt))+abs(D_tilt(dist)*sin(tilt))
d_max <- function(dist,tilt) (sqrt(D_dist_perp
    (dist,tilt)^2+D_or(dist)^2))/2

# maximum distance and area calculations at fixed
    tilt value (tilt = 0.12 radiant)
area <- function(dist,tilt=0.1221730,dist_err=1,
    tilt_err=0.20/(360/(2*pi)),or_err=1.8/(360/
    (2*pi))) (abs(dist_err*cos(tilt))+abs(2*dist*sin
    (tilt_err/2)*sin(tilt)))*2*dist*sin(or_err/2)
d_max <- function(dist,tilt=0.1221730,dist_err=1,
    tilt_err=0.20/(360/(2*pi))) sqrt((abs(dist_err*
    cos(tilt))+abs(2*dist*sin(tilt_err/2)*sin(tilt)))
    ^2+(2*dist*sin(or_err/2))^2)/2

# Generated sequences:
distance <- seq(1,225,1)
tilt <- seq(0,14/(360/(2*pi)),0.1/(360/(2*pi)))
error <- matrix(nrow=length(distance),ncol=
    length(tilt))
for (i in distance) {
error[i,] <- d_max(i,tilt) }
```