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NONCONTACT METHOD FOR ESTIMATING ELLIPTICITY AROUND THE GIRTH OF A FREE-RANGING DOLPHIN

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Abstract. *In recent years, wild dolphins that live in coastal areas that overlap with areas of human activity are being greatly affected by the increasing conflict with human activities. Therefore, their growth rate and nutritional status must be monitored to aid in their conservation. A method of measuring them has not yet been established, and research has not progressed. Therefore, we aim to develop the elemental technologies necessary for constructing such a system, which would contribute to the health diagnosis of wild dolphins. This paper proposes a novel method to estimate the ellipticity around the girth of free-ranging wild dolphins, and clarify their growth and leanness. The purpose of this study is to help conserve the dolphin population by capturing changes over time.*
Keywords: Dolphin conservation, Free-ranging, Leanness, Non-contact, Ellipticity estimation, Approximate parabola

1. **Introduction.** Anthropogenic activities, e.g., underwater construction, dredging, heavy fishing, recreational activities at the shore, shipping, and traffic, have serious impacts on wild aquatic animals, including dolphins, by destroying their natural habitats, decreasing their food resources, and increasing anthropogenic noise in the habitats [1]. To conserve wild dolphins, their health must be constantly monitored.

For animals, even for humans, the body length and girth are important criteria that indicate the health condition (especially the nutritional status), as well as the reproductive status (e.g., the body length is related to sexual maturity, and the pregnancy status can be determined by the girth). Thus, these parameters are important basic information for monitoring the health condition of a population [2].

However, it is extremely difficult to measure these parameters in free-ranging wild dolphins underwater. Therefore, researchers heavily rely on dead and/or stranded dolphins from the population to measure the body length and girth [3]. Some research teams catch dolphins to determine their health conditions [2]; however, this method is expensive and places immense stress on the dolphin. Consequently, noninvasive methods to measure a dolphin's length and girth are eagerly anticipated. We have already developed a noninvasive system for measuring the body length of free-ranging wild dolphins [4].

A noninvasive girth measurement for wild cetaceans (whales and dolphins) is rare. Recently, Christiansen et al. [5] presented a method to obtain the girth of large whales by

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fitting ellipses to the whale's body in drone-video footages, and thereby estimated their total body weight. They estimated the ellipse height and width based on the lateral and dorsal sides of the whale. This method can be applicable to slow and parallel-surfacing large whales; however, it is difficult to adapt for quick and bent-surfacing smaller dolphins.

In this paper, we propose the new method necessary for constructing a system to estimate the ellipticity of a cross-sectional view around the girth of individual wild dolphins. The "leanness" criterion can be obtained without contact, using a video camera with underwater housing or water-resistant video camera. When monitoring wild animals over a long period, the system should be compact and easy for anyone to handle and use [6]. Then, the changes in the nutritional state of the population could be observed over time by monitoring the girth of wild dolphins without causing them any stress.

2. Proposed Method.

2.1. Overall block diagram. Figure 1 shows the overall block diagram. First, videos of free-ranging dolphins were taken using an underwater video camera. As a precaution, it was supposed that the dolphin's body axis and the camera's optical axis are almost perpendicular to each other, and the dolphin is rotating around its body axis. Next, the video frames that meet the conditions were extracted from the obtained video. The still images were captured, and the dolphin areas were extracted. The lengths of the line segments were then measured, as described later in text.

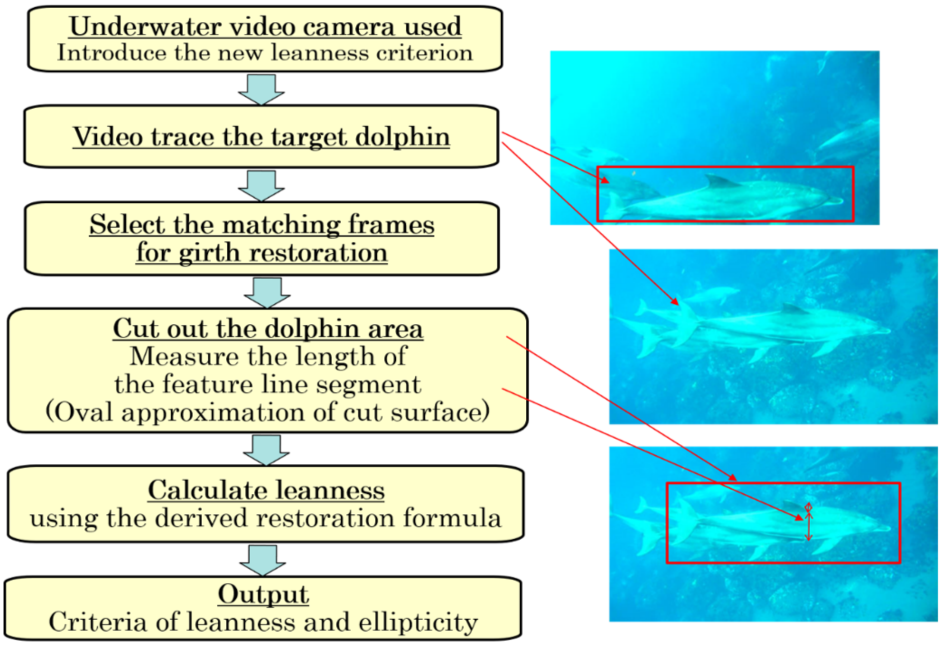


FIGURE 1. Overall block diagram for estimating a dolphin's leanness

Since the unit of measurement can be pixels on a monitor screen or centimeters on a sheet of printed paper, this plays a role of normalization in postprocessing. This increases the processing flexibility and eases the system usage. Furthermore, ellipticity α was obtained using our proposed formula, after which, normalized parameter β was achieved and output as the leanness criterion.

2.2. Definitions and symbols. The counter lines of the cross section around a dolphin's girth can be well approximated by an ellipse [5]. This aspect is shown by the dashed lines in the images on the left side of Figure 2. Dolphins and whales are cetaceans and have similar body structures; hence, this fact may be applicable to dolphins. In fact, the developed method is applicable not only to dolphins but also whales, as a weight index.

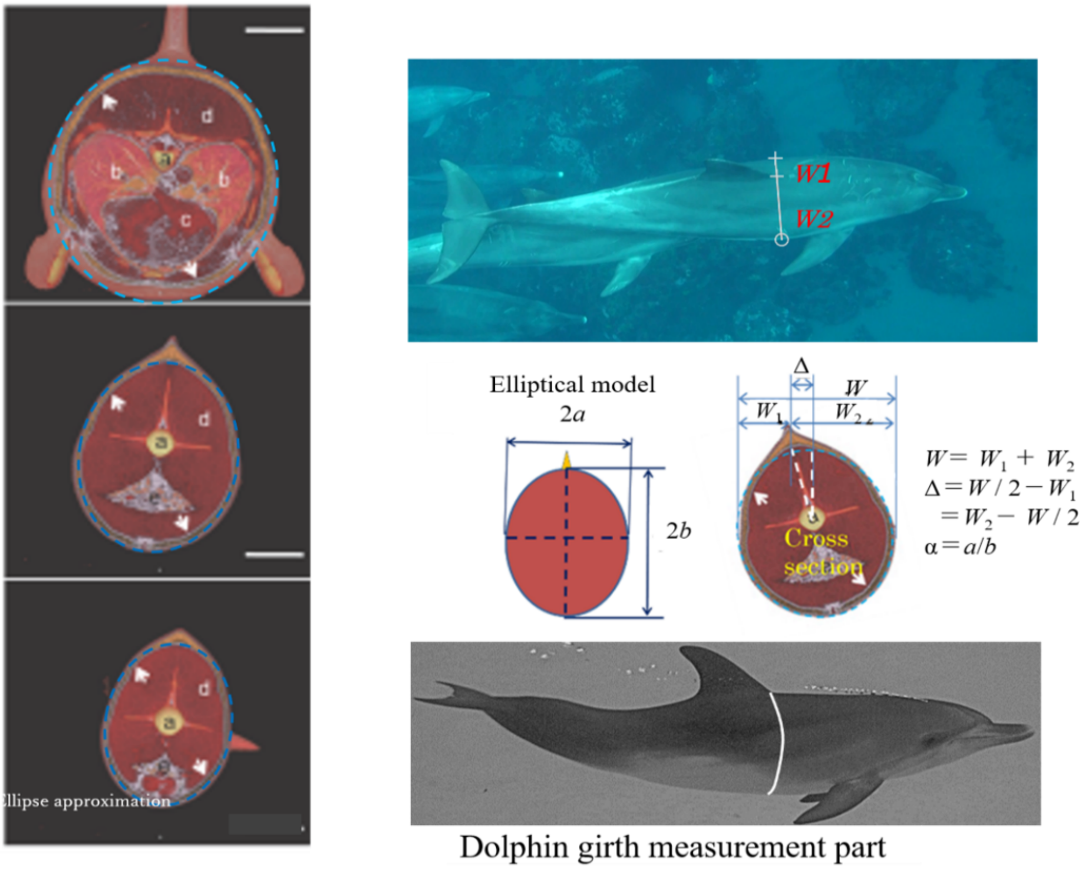


FIGURE 2. Ellipse approximation and parameters on a dolphin cut plane [7]

This section describes a method for determining the ellipticity, supposing that the cross section of a dolphin is elliptical.

Let us first define some symbols, as measured at the tip of dorsal fin:

W: Width (perpendicular to the body axis through the anterior origin of the dorsal fin).

W_1 and W_2: Lengths of the line segments on the left and right sides of the dorsal fin, respectively:

$$W = W_1 + W_2. \tag{1}$$

Δ: Distance between the center of the width and anterior origin of the dorsal fin:

$$\Delta = W/2 - W_1 = W_2 - W/2. \tag{2}$$

α: Ratio of the length of the minor axis to that of the major axis of an approximated ellipse:

$$\alpha = 2a/2b \ (a < b). \quad \alpha = a, \text{ when } b = 1, \text{(Ellipticity)}. \tag{3}$$

β: Ratio of the values of W when $\Delta/W = 0.4$ ($W_{0.4}$) and when $\Delta/W = 0$ (W_0).

These aspects are shown on the right side of Figure 2, and the aspect of β will be shown later in Figure 4. α and β are important parameters, as explained in Section 3, and can be derived from Δ and W through mathematical calculations (see the Appendix for the derivation). β is used as the leanness criterion:

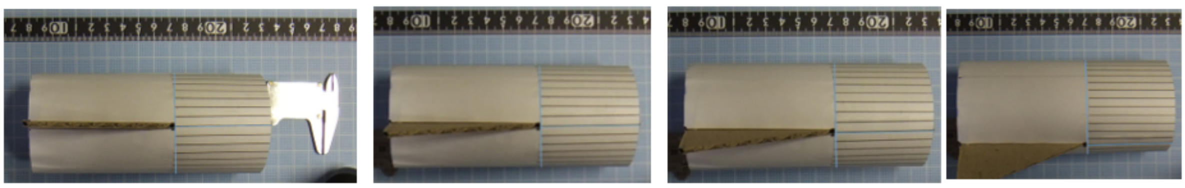
$$\beta = \left(\left(9 + 16 \times \alpha^2\right)^{(1/2)}\right) \Big/ 5. \tag{4}$$

Here, β is obtained by $W_{0.4}/W_0$, where $W_{0.4} = W$ ($\Delta/W = 0.4$) and $W_0 = W$ ($\Delta/W = 0$). In this study, $\beta = 0.4$ because it is possible to experimentally obtain values up to this level, in most cases. A value of 0.5 or more is difficult to obtain for a moving dolphin. In addition, α could be obtained from an inverse quadratic function. If we use the approximated inverse function, β may be easier to obtain. The proposed system works well when the optical axis of the video camera is perpendicular to the body axis. However, the captured still images should be clear and distortion-free.

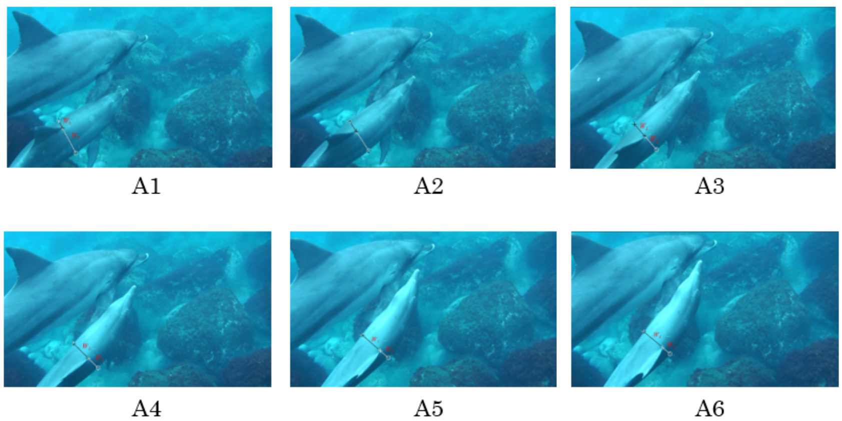
2.3. **Experiments.** The effectiveness and high flexibility of the proposed method were confirmed through mock experiments using hand-made elliptical paper cylinders [E] and a real video of a dolphin [R]. [E], [R], and [E, R] indicate the use of the former one, the latter one and both, respectively. The experimental process is as follows.

[E] [Construction of elliptic cylinders.] At this time, it is difficult to determine α; therefore, we first constructed elliptic cylinders with the appropriate ellipticities. Then, the values could be obtained by measuring α: $\alpha \in \{0.935, 0.765, 0.653\}$.

[E] [Shooting: Elliptic cylinder photographs.] We continuously shot still images while rotating the elliptic cylinders every five degrees. Because high accuracy is not required, the rotation angle may be appropriate. We extracted an elliptic cylinder from the images and its parameters; see Figure 3(a).



(a) Examples of rotated images of an elliptical cylinder



(b) Examples of dolphin images captured from a real video (Rotating around the body axis)

FIGURE 3. Examples of two experiment types used for algorithm evaluation

[R] [Shooting: Video of a dolphin.] We shot a video of a dolphin in the free-ranging state. The restraint conditions at the time of shooting are as follows. 1) The dolphin's body axis should be perpendicular to the camera's optical axis. 2) The rotations must be around the body axis. Then, we selected the frames suitable for restoration, cut out the dolphin, and extracted the parameters; see Figure 3(b).

[E], [R] [Selection and cutting out of dolphins to be analyzed.] We measured the length of the feature line segments, W_1, W_2, and W (any unit (cm, pixels) is acceptable, see Figure 2).

[E], [R] [Parameter calculation, graph: $(x, y) = (\Delta/W, W)$, $y = f(x)$.] We added symmetric data with respect to Δ/W (x axis) ($x = -\Delta/W$). When we drew an approximate parabola, the first-order coefficient was desired to be extremely close to 0. Because it is symmetrical with respect to the y axis, we define the new $W(x) = f(x) + f(-x)$; then, $W(-x) = W(x)$.

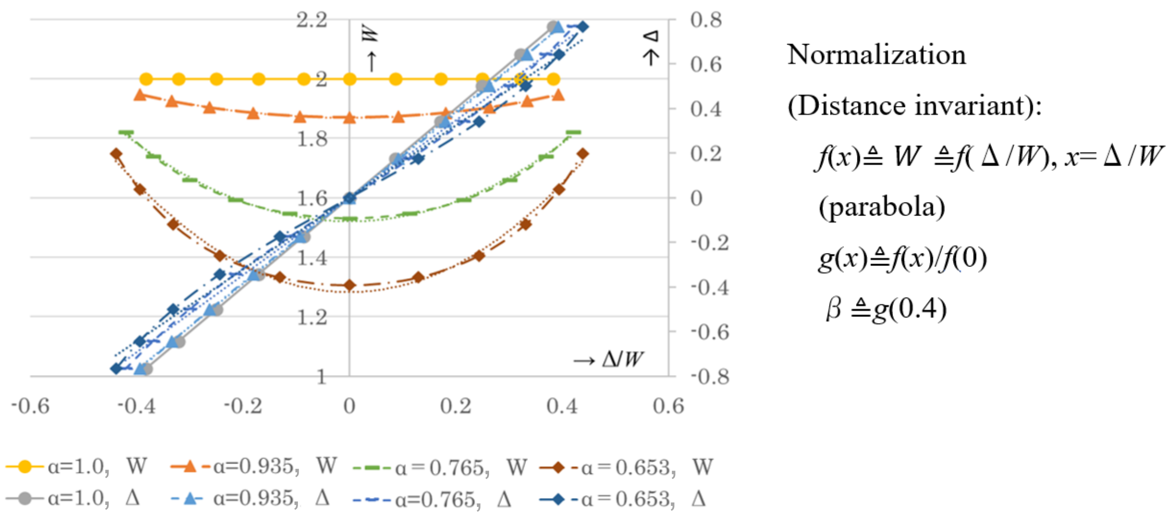
[E], [R] [Acquisition of α and β.] α was obtained by the proportional distribution from the reference graph calculated in advance. β was calculated using Equation (5). Both α

and β can be indicators of leanness; we normalized them by dividing by $f(0)$ to eliminate the difference in the distance between the camera and dolphin (**Distance-Invariance**).

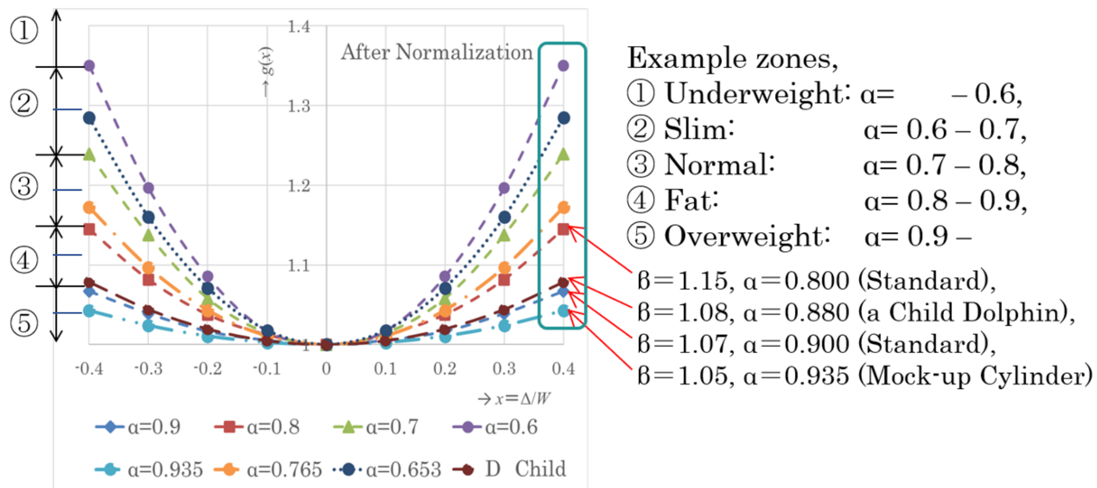
$$g(x) = f(x)/f(0); \quad \beta \triangleq g(0.4) \tag{5}$$

Only the six images in Figure 3(b) were used for restoration. The necessary equipment includes an underwater video camera and a personal computer. As such, we obtained $\alpha = 0.88$ and $\beta = 1.08$. Although there is room for improvement in accuracy, we confirmed that it is possible to estimate the ellipticity of the cross section. This is the basis for the noncontact leanness estimation.

3. **Experimental Results Using Elliptic Cylinders and Real Video Frames.** Experiments were performed according to the procedure described in the previous section. Figures 4(a) and 4(b) show the results. In Figure 4(a), the horizontal axis (x) represents Δ/W, and the vertical axis (y) represents W (the central axis) and Δ (the right axis). Good approximations of W and Δ were obtained through quadratic and linear equations, respectively. The approximate curves are represented by dotted lines. When



(a) Relations among $x = \Delta/W$, $y_1 = W$, and $y_2 = \Delta$



(b) Evaluation measure after normalization

FIGURE 4. Relations between each parameter (Horizontal axis: Δ/W, Major axis = 2)

unknown data are obtained, they can be calculated by overlaying them on this graph and proportionally distributing them.

Figure 4(b) shows the normalized curves, $g(x)$, as shown in Figure 4(a). As a reference, the curves corresponding to $\alpha \in \{0.6, 0.7, 0.8, 0.9\}$, obtained by calculation in advance, are shown by dashed lines. The results of the mock experiments and a child dolphin are shown by other line types, corresponding to $\alpha \in \{0.653, 0.765, 0.965\}$. This graph shows that the results of the mock experiment are just within the corresponding range of the theoretically obtained graph. As described later, the numerical values were obtained with fairly good accuracy.

Figure 4(b) shows that $\beta = g(0.4)$ may be used as the leanness criterion (overweight and underweight). The larger the value of β, the leaner the dolphin, and the smaller its value, the fatter the dolphin. Distance-invariance was realized using Equation (5). This is an important concept, which could indicate the application of the system, regardless of the distance between the target and camera.

The effectiveness of the proposed method was confirmed using video frames of a real dolphin. The true values of the actual dolphin are unknown; they could not be evaluated. However, $\beta = 0.884$ seems to be a reasonable value. These values are listed in Table 1, along with the estimated values of α and β obtained through experiments, in which the effectiveness of introducing β can be confirmed. Figure 5 shows a good approximation between the mock experiment (solid line, marker ●) and the theoretical value (dashed line, marker ▲) used as a reference.

TABLE 1. Estimation of α and β and evaluation of error

	Reference			
α_1	0.6	0.7	0.8	0.9
β_1	1.350	1.239	1.145	1.067

	Elliptic cylinders			Dolphin
α	0.653	0.765	0.935	(*)
β	1.285	1.172	1.043	1.078
α'	0.661	0.780	0.915	0.878
	Error			
$\alpha' - \alpha$	0.008	0.015	−0.020	−
	1.21%	1.92%	−2.19%	−

(*) True value unknown

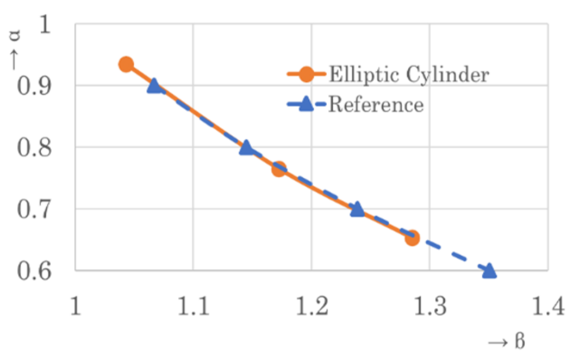


FIGURE 5. Two nearly equal lines

4. **Conclusions.** Surprisingly, it has been difficult to find 3D models of dolphins that are strictly taken from measurements of real dolphins. Even if a computed tomography scan on land is used, the abdomen will be dented, owing to gravity. If we can measure them properly in water, the technique can be applied to various studies. Because the proposed method is applicable to free-ranging wild dolphins, such weak points could be overcome. Because the cross section of a dolphin can be well approximated by an ellipse, an inexpensive and simple system could be constructed by using one video camera and one PC.

In the future, true values of the girth of free-ranging dolphins could be obtained and verified using more real images, and improving the robustness and stability of the algorithm. When multiple video cameras are used, we can effectively obtain more suitable images and more accurate results. The results of our experiments confirmed the effectiveness and flexibility of the proposed method.

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Appendix. Calculation of α from W and Δ.

If the ellipse with a $2a$ minor axis and $2b$ major axis rotates θ degrees, the (x', y') of the original ellipse can be explained through the following formula by using the (x, y) of the rotated ellipse (see Figure 6):

$$x' = x\cos(-\theta) - y\sin(-\theta) = x\cos\theta + y\sin\theta = a\cos\beta, \tag{6}$$

$$y' = x\sin(-\theta) + y\cos(-\theta) = -x\sin\theta + y\cos\theta = b\sin\beta, \tag{7}$$

$$x = \left(a^2\cos^2\theta + b^2\sin^2\theta\right)^{(1/2)} \times \sin(\beta+\gamma) \quad \left(-180^\circ \leqq \gamma \leqq 180^\circ\right), \tag{8}$$

where $-1 \leqq \sin(\beta+\gamma) \leqq 1$, then

$$\min(x) = -\left(a^2\cos^2\theta + b^2\sin^2\theta\right)^{(1/2)}, \tag{9}$$

$$\max(x) = \left(a^2 \cos^2 \theta + b^2 \sin^2 \theta\right)^{(1/2)}. \tag{10}$$

Then,

$$W = 2 \times \left(a^2 \cos^2 \theta + b^2 \sin^2 \theta\right)^{(1/2)}. \tag{11}$$

Now,

$$\Delta = b \sin \theta, \text{ and } a = b \times \alpha; \text{ then, } W = 2 \times \left((b \times \alpha)^2 + \left(1 - \alpha^2\right) \times \Delta^2\right)^{(1/2)}. \tag{12}$$

Then, we obtain

$$\Delta/W_0 = 0,\ \Delta/W_{0.4} = 0.4; \text{ then, } \beta = W_{0.4}/W_0 = \left(\left(9 + 16 \times \alpha^2\right)^{(1/2)}\right) \Big/ 5. \tag{13}$$

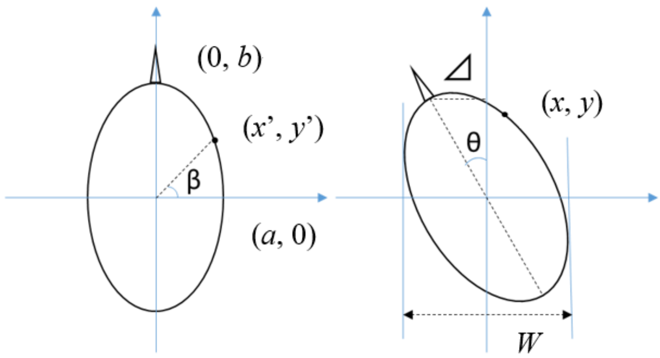

FIGURE 6. Calculation of α from W and Δ