A feather precision measurement method

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Abstract. The methods of measurement of the microscopic and macroscopic morphology of feathers are discussed. A three-dimensional coordinate measuring machine and optical microscope are used together, that is, the macroscopic size of the feather is measured using the detection technology of the three-dimensional coordinate measuring machine, and the optical microscope is then used. The static accuracy error produced by the measurement result is (2.9064–4.0235) um, which is much smaller than the measurement error of 0.5 mm of the millimetre measuring ruler; The microscopic dimensions of the plume of the feather plume are measured by microscopy; the result is accurate to micron level, and the gradated scale is accurate to ± 0.5 mm. This study contributes to basic theoretical research in the fields of feather morphology, fractal analysis, and ecology.

1. Introduction
Natural selection gives birds colourful feathers (figures 1(a)-1(c)), and the flying behaviour of bird feathers has attracted more attention [1,2]. In the related research involving feathers, the range of measurement of feathers is an important reference index for judging bird species. Therefore, when the feather parameter is measured at large-scale, a three-dimensional coordinate measuring machine (micron-level) is used for precision measurement, and the measurement accuracy is much greater than that when using a measuring ruler (millimetre gradations). When a feather parameter is measured at small-scale, it is measured using an optical microscope (or scanning electron microscope (SEM)) for which the accuracy is of the order of microns. Use of a three-dimensional coordinate measuring machine with an optical microscope to overcome the defects of the measurement range and measure feather size parameters is proposed.

The three-dimensional coordinate measuring machine is a precision measuring device widely used in measuring the size of mechanical parts: it uses a laser-triggered measuring head for high-speed measurement. It has a large measuring range, fast response speed, and sensitive triggering. It is a micro-precision measuring tool.

Measurement of the size of the wings, feathers, and body of a bird is used to determine the ratio between the length of the wing and the fuselage, and is important in aircraft structural design. During three-dimensional (3-d) micro-surface morphology measurement [1], Jenni measured wing-length [3-5], Fl and F6-9 bending alignment in 5329 live birds of 51 species, using half-millimetre scale, where scale detection error is ± 0.5 mm [3]. The potential migration and differentiation of birds overwintering [6] maintains the natural phenomenon of species survival, not only indicating the importance of feathers for their survival, but also the bird niche (the ecological niche thereof) [7] determines the flight parameters of bird feathers. Access to food and escape from danger are thus predicated, and species survival is the result of natural selection. In addition, factors other than
migration (dominance hypothesis, arrival time hypothesis, body-size hypothesis, Allen’s rule, the resource partitioning hypothesis, and other potential limitations) also affect wing-length [8].

![Figure 1. Natural selection gives birds colourful feathers (a) Embroidered bird (b) Pigeon (c) Parrot.](image)

To analyse feather morphology, the measurement of feather leaf length currently involves use of a scale (to ± 0.5 mm) and blade area measurement using Adobe Photoshop 1 Version 5.0.2 (to ±0.1 mm²) [9]. Studies have shown that the bird feather wingtip shape exhibits continuous pointedness [10], and the regional distribution of pointedness has important reference value for determining species distribution and mastering the ecological distribution thereof [11]. After collecting feather samples [12], statistical analysis (using SPSS™ software) [13-19] and binomial model methods [20,21] have been used. Other studies have shown that the wing beat cycle of bird flight begins with the wing reversed and the main feather rotates slightly to create a gap between successive feathers. The wing begins to move forward and upward, and lift is generated by the adjustment of the aerofoil [22]. According to research, there is a potential growth curve of bird feathers in the growth phase, that is, the growth of the feathers was described by Gompertz equations. It is a growth curve formed using non-linear regression [23,24]. In addition, studies have shown that feather morphology is related to bird behaviour and the prevailing environment, and shape variables are the most important component of morphological changes. Linear correlation measures are used to measure the shape and size of birds. Bird flight behaviour is characterised by habitat, dynamic flight (continuous tapping), flapping, gliding, and flying. The bird observes the surrounding environment from its habitat. When gliding, the wing stretches from the body in a fixed position without tapping, and the flight path is more or less straight. Therefore, when measuring the length of the wing, the wings on both sides should be fully extended. The power flight of the birds has two forms of continuous tapping and power glide therein [25,26].

Here, we proposed a precise measurement method for measuring the microscopic and macro-length dimensions of bird feathers, using an optical microscope and the high-precision measuring equipment on a three-dimensional coordinate measuring machine. The two are used together to measure various parameters thus providing references for researchers in morphology, fractal analysis, and ecology.

2. Materials and methods

2.1. Materials

The experimental materials were selected from white and black bird feathers and tail feathers (for example, goose feathers). They were immersed in, and disinfected with, a 75% alcohol solution, dried naturally, and used as needed. We applied double-sided adhesive tape to fix the feather position.

The experimental equipment included: a measuring ruler, an optical microscope, a FLY1086 model 3-d measuring machine, and a camera.
2.2. Method

2.2.1. Measuring the microscopic size of the feather-shaped plume. The knotted plume of the black feather was identified and fixed on the slide using double-sided adhesive tape. The specimen was placed on the optical microscope stage for microscopic observation, photography, and measurement.

The measurement methods of macro and micro-forms of feathers are shown in figure 2. The measurement of the macroscopic shape of the feather involves use of a measuring ruler (figure 2(A)). The microscopic morphology of the feather was imaged and filtered under an optical microscope (figure 2(B)). The micromorphological measurement method used on the knotted plume is shown in figures 2(C) and 2(D).

![Figure 2](image)

Figure 2. Measurement methods for macro and micro-forms of feathers. (a) Macroscopic morphology measurement, unit: mm. (b) Microscopic morphology under optical microscopy, unit: um. (c) Microscopic morphology measurement of knotted feathers. (d) Microscopic morphology measurement of knotted feathers.

2.2.2. Three-dimensional coordinate measuring machine measurement method. This experiment uses a FLY1086 model 3-d coordinate measuring machine as a high-precision measuring equipment, with a range of measurement of $X = 800$ mm, $Y = 1000$ mm, $Z = 600$ mm, and a resolution of 0.01 um was used. The chosen 3-d coordinate precision measuring machine includes: various bases, work benches, columns, guides, drive systems, measuring systems, electrical control cabinets, measuring heads, computer and control software, and printers. The measuring principle is follows: the measuring system used in the three-dimensional coordinate precision measuring machine is composed of a grating ruler and an infrared scanning system. During the measurement process, when the 3-d measuring head is in contact with the surface of the object to be measured, a sampling pulse is emitted, and the coordinates of the centre of the measuring head at this time are locked and saved. By measuring the surface several times, the spatial coordinate measurement head coordinate measuring machine equation can be obtained to determine the size and shape of the workpiece.

Two black feather tail feathers and one fly-feather were used, and they were washed and dried with 75% alcohol solution, and fixed on the high-level block of the 3-d coordinate measuring machine operating platform, and fixed with double-sided adhesive tape. Then the test data were checked on a point-by-point basis. The three-dimensional coordinate measuring machine and its precise measurement process for feathers are shown in figure 3. According to the error formula: the measured error value is:
\[ \Delta L = L_0 \text{ (standard value)} - L(\bar{x}) \text{ (measured value)}. \]

Figure 3. 3-d coordinate measuring machine and its precise measurement process.

It should be noted that the three-dimensional coordinate machine is suitable for the measurement of large feathers, and the precise measurement of small dimensions (for example, the plume) requires measurement by optical microscopy (measuring overall feather lengths required their combined use).

3. Results and discussion

From measured results of knotted feather twigs (figure 4), the diameter of the knotted plume is 6.08 um to 10.05 um, and the diameter of the curve (indicated by the thick line in the blue diamond in the
The section length is 69.26 um to 101.18 um, and the curve shape formed by the section length (indicated by the black thick line in the figure) fluctuated to a significant extent. The aspect ratio is 7.64 to 14.88, and the curve formed by the aspect ratio (indicated by the thick line in the green triangle of the figure) tends to be linear (represented by the thin red line in the figure).

From the analysis of the distribution of the measurement results of the length and diameter of knotted feathers (figure 5), the diametral distribution of the knotted plumes is within 6.08 um to 10.05 um, and the section length is 69.26 um to 101.18 um, and the distribution thereof is concentrated centrally.

![Figure 5. Analysis of the distribution range of the measured lengths and diameters of knotted plumes.](image)

![Figure 6. Analysis of the measured results of the feathers (3-d measurement coordinate machine).](image)

The analysis of the measured results taken from the three-dimensional coordinate machine is
shown in figure 6: the difference between the total length of the tail feathers 1 and 2 (red and yellow marking areas) of the same species, the diameter of the branching feathers, the length of the branch, and the aspect ratio were small, the total length between the tail feathers of the same species and the fly-feathers (green marking area), the diameter of the branch-like plume, the length of the knot, and the ratio of the aspect ratios were quite different.

According to the user’s manual for the FLY1086 three-dimensional coordinate measuring machine used in the experiment, the static accuracy error of the space measurement of the measuring machine is:

\[ E \leq (2.9 + L/250) \mu m \]

The feather length measurement range of this example \( L \) is (1.600-280.8804) mm. The corresponding static accuracy error is (2.9064-4.0235) um. The error in the measured results is much less than the 0.5 mm error on the millimetre scale. The accuracy measurement error further indicates that the coordinate measuring machine is suitable for use in the case of measuring the macro-size of feathers in this case.

4. Conclusion
When measuring the micro and macro-length dimensions of the feather as a whole, it is recommended to use an optical microscope and a high-precision measuring device such as a three-dimensional coordinate measuring machine.

The total length of the tail feathers of the same species, the diameter of the branching plumes, the length of the branches, the length-to-diameter ratio differ little; the total length between the tail feathers and the flying feathers of the same species, the diameter of knotted feathers, and the length of the knot, differ significantly when expressed as aspect ratios.

The feather length measurement range of this example \( L \) is (1.600 to 280.8804) mm. The corresponding static accuracy error is (2.9064 to 4.0235) um. The error in the measured results is much less than the ± 0.5 mm error associated with the use of a millimetre gradated scale. The accuracy measurement error further indicates that the coordinate measuring machine is suitable for use when measuring the macro-size of feathers in this case.

The distribution of the length and diameter of the knotted feathers of the feathers is concentrated. The diameter distribution of the knotted plumes is 6.08 um-10.05 um, and the section length is 69.26 um-101.18 um.

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