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Quantifying the precision and accuracy of the MicroScribe G2X three-dimensional digitizer

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ABSTRACT

Portable three-dimensional digitizers facilitate the "digitize" and "compare" operational areas of Virtual Anthropology. However, these measurement devices must be adequately accurate and precise for their intended purpose. We determined that varying the arm configurations led to standard deviations less than 0.23 mm. The distances between pairs of points among 10 points on a reference object at 16 locations within the workspace had an average error of 0.239 mm; only three of the 720 measures had an error greater than 1 mm. Through assessing geometric morphometry, the average landmark standard deviation of the 10 points at 16 locations across the workspace was only 0.12 mm. The different areas of the workspace and different arm joint configurations do not meaningfully influence the measurement precision and accuracy. Therefore, the MicroScribe G2X has suitable accuracy and precision to be an appropriate research tool for many anthropological, forensic and biomechanical studies.

1. Introduction

"Digitize" is one of the six operational areas of Virtual Anthropology, and a necessary step for other areas such as "compare" and "share" (Weber, 2014, 2015). Portable three-dimensional digitizers facilitate these areas by non-invasively recording the location of specific points in three dimensions. They provide a relatively inexpensive and non-invasive way to identify and record three-dimensional points. They are an important tool for numerous fields including anthropology (Hughes et al., 2012; Ross and Williams, 2008), biomechanical modelling (Li et al., 2015), and musculoskeletal research (Gillespie et al., 2011; Meier and Meier, 2006; Ravichandiran et al., 2010; Schenk et al., 2013). The MicroScribe G2X three-dimensional digitizer (Revware Inc, Raleigh, North Carolina) is a counterbalanced, multi-joint apparatus with a 1 m^3 workspace. It can record individual coordinates or stream coordinates for a finite period of time. The manufacturer states that the point accuracy error of the G2X is 0.23 mm (Immersion Corp, 2013). Although international standards have been developed to describe the measurement characterization of 3D measurement systems based on touch probes (summarized in Acko et al. (2012)), these standards have not been considered for the Microscribe. Furthermore, we are not aware of any studies that have evaluated whether the accuracy varies within the workspace. Importantly, researchers have not questioned the accuracy of the MicroScribe device; in contrast, one study used the MicroScribe as the gold standard for their assessment of two photogrammetric systems (Gornick, 2011). The G2X is constructed of serial linkages with redundant joints (Fig. 1) and therefore the stylus tip can reach a desired coordinate using different combinations of joint arm angles (configurations; Video S1), giving the user the ability to assess objects with complex shapes such as skulls (Ross and Williams, 2008). This may introduce systematic error and thereby impact the precision and accuracy of the device, although these factors have not yet been investigated. The scarcity of studies evaluating the instrument measurement properties starkly contrasts the large number of studies that have evaluated human repeatability (Ross and Williams, 2008; Sholts et al., 2011; Sládek et al., 2012), and error between multiple observers (Ghoddousi et al., 2007; Ross and Williams, 2008; Sládek et al., 2012) or measuring techniques (Ghoddousi et al., 2007; Sládek et al., 2012).

Due to the MicroScribe's widespread use, it is important to be confident that it has adequate precision and accuracy, regardless of the arm's configuration or location in the workspace. The purpose of this paper was to evaluate the accuracy and precision of the MicroScribe G2X instrument at different locations in the workspace.

2. Methods

An aluminium staircase-shaped reference object (approximately $15 \times 15 \times 10\ cm^3$, with stair height of approximately 2.5 cm) was constructed containing 10 points (punched divots), arranged at

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2212-0548/

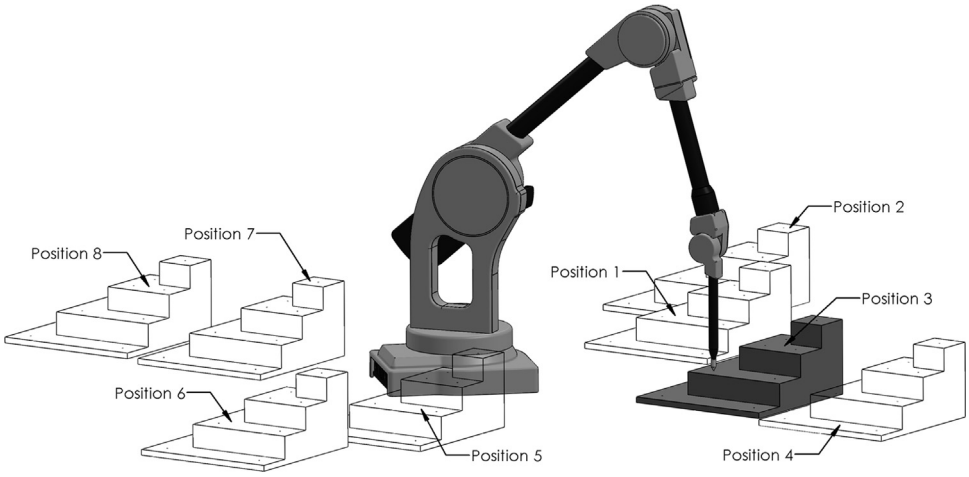
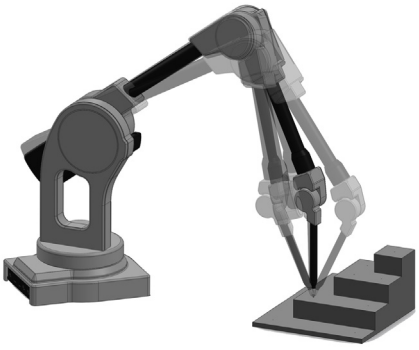


Fig. 1. Illustration of the relative spatial relationship between the MicroScribe G2X apparatus and the eight positions of the reference object. Note that only the locations of the reference object at the lower level are illustrated, and that the other eight positions are located approximately 200 mm above each of these lower positions.



Video S1. Video illustrating different configurations of the MicroScribe arm for locating the same point in three dimensions. Coordinate data were streamed while the arm was rotated in a circular motion; these data were used to calculate precision as the standard deviation of the coordinates. A video clip is available online. Supplementary material related to this article can be found online at http://dx.doi.org/10.1016/j.daach.2015.03.002.

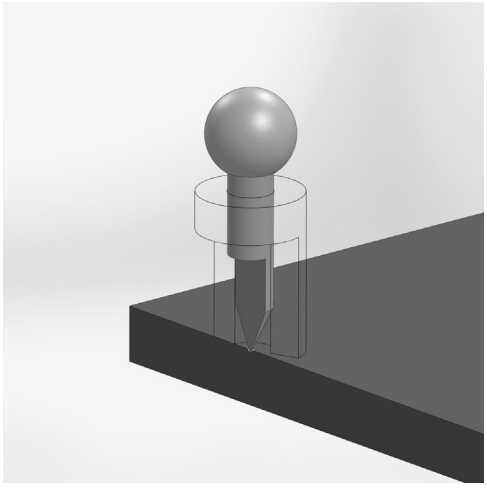


Fig. 2. Cutaway view of the system for measuring the location of the punched divots on the reference object using the coordinate measuring machine. A pointed pin slid in the bushing to locate the punched divot, and the 1 cm spherical head allowed the coordinate measuring machine to locate the centre of the sphere.

various locations on four different planes (Fig. 1). The specific *X*, *Y* and *Z* coordinates of these points were measured using a coordinate measuring machine (DEA Swift A000, Hexagon Metrology, Cobham, Surrey, Great Britain) and probing system (DEA TF8, Hexagon Metrology, Cobham, Surrey, Great Britain; rated volumetric accuracy of 5.1 μm). Given that the coordinate measuring machine measures the centre of spheres rather than the location of punched divots, we used a ball-headed pin sliding in a bushing to preserve the relative location of the punched divots, but offset them off the surface of the plate (Fig. 2). The accuracy and precision measurements involved measuring the three dimensional locations of divots (the ball-headed pin and bushing were not used for the MicroScribe) on the reference object at 16 pre-determined locations in the digitizer's 1 m^3 capture volume; near and far locations to the front, back right and left sides of the MicroScribe, at both low (level A; tabletop) and high levels (level B; approximately 20 cm higher; Fig. 1). All data were collected using MicroScribe Utility Software (MUS version 5.1.0.0, Revware Inc, Raleigh, North Carolina) and exported directly into Microsoft Excel (Version 2007, Microsoft Corp., Redmond, WA, USA) for further analysis. All testing was performed at room temperature, although the precise temperature was not recorded and there may have been small differences in temperature which might introduce error due to thermal expansion of our test specimen.

2.1. Precision

The MicroScribe's stylus tip was seated in a divot on the reference object and the MicroScribe arm was rotated in a circular motion, while coordinate data were streamed at 10 Hz for 10 s yielding 100 coordinate points (Video S1). The stylus was maintained within 30° of the *Z* axis so that the stylus tip remained firmly seated in the divot throughout the trial. Precision was quantified using the standard deviations of the *X*, *Y*, and *Z* coordinates, which were calculated for the sets of streamed data at each of the 16 locations within the MicroScribe's workspace.

2.2. Accuracy

The reference object was clamped in position at one of 16 locations relative to the MicroScribe apparatus (Fig. 1) and the individual coordinates of the 10 points (divots) on the reference object were captured at each location. This approach is conceptually similar to the ISO 10360-2 "E" standard that involves measuring the