The Great Wall of China can be Seen from Space

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Abstract
Whether the Great Wall of China is visible from space by naked eye has become a space-based myth. Conflicting stories told by astronauts have been reported in various media. Several scholars also tried to give a much needed scientific answer to the question through their own research. Recently, Chinese scholars Dai et al. published their analysis based on visual acuity of point objects and concluded that astronauts cannot see the Great Wall of China from space. However, our analysis based on the human's visual acuity of linear objects concludes that the Great Wall can be seen at the altitude up to about 500 km. Some environment conditions on the ground may dampen the chance of a successful observation.

I. INTRODUCTION

Whether the Great Wall of China can be seen from space by naked eye is a topic that has been discussed by scientists and astronauts for years. Some astronauts, e.g. Eugene Cernan (Felix, 2004) and Valentina Tereshkova (2004), said that they saw the Great Wall from their spacecrafts while others, e.g. William Pogue (Pogue, 1991), Roberta Bondar (Wynnyckyj et al., 1999), and Liwei Yang (Britt, 2003) claimed that they did not. Trying to find a scientific answer to the question, Chinese scholars Dai et al. (Dai et al., 2005,2007) recently published their analysis based on visual acuity of human eye to point objects. They believe that the Great Wall of China, assuming an average width of 10 m, cannot be seen from the altitude of 62.5 km or above, not to mention from spacecraft at 160 to 320 km above the Earth surface. They also claim that this is a definitive answer to the question and should be used as a theoretical basis in the future dealings of the subject. Is it really the final definitive answer? Our following analysis however concluded that the opposite is true.

II. VISUAL ACUITY

The primary components of human eyes are a lens system and a receptor system of the retina which contains an arrangement of receptor cells named rods and cones. For an object to be detected by the human eye, it has to form an image of minimum dimension on the retina. The minimum size an object must possess in order to be perceived is normally expressed by the angle it subtends in the eye—visual acuity (α) as illustrated in Figure 1.

Visual acuity angle is defined as the following (measured in arc minutes):

$$\alpha = 21{,}600 L / 2\pi D \quad (1)$$

L is the size of the object; D is the distance between the object and the eye.

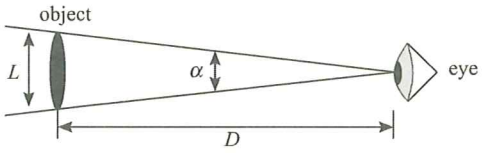

Figure 1. Illustration of visual angle

For normal vision under the normal conditions of illumination, it is generally accepted that this angle is one minute of arc if objects are point-shaped and 0.5 seconds (or 0.0083 minutes) if objects are line-shaped (Davson, 1990). The reason this angle is much smaller for linear objects than point objects, as explained by Hecht and Mintz (Hecht et al., 1939), is that although the width of the lines is small but the length of lines helps to create the variation of luminance on the retina which is adequate to cause a differential cone stimulation for brain to perceive the object.

III. "THE GREAT WALL OF CHINA CANNOT BE SEEN FROM SPACE" IS INCORRECT

Dai et al. (Dai et al., 2005,2007) tried to use visual acuity theory in their analysis but mistakenly employed the theory for point objects. Assuming a 10 m width of the Great Wall, they calculated that the maximum altitude for the Great Wall to be seen is about 62.5 km. Since most spacecrafts orbit the Earth at the altitude of 160 to 320 km, they therefore concluded that astronauts cannot see the Great Wall of China in space.

First of all, a normal vision is usually between 0.5 to 1 minute of visual angle (Bruce et al., 1996), rather than 6 minutes as stated by Dai et al. Six-minute visual acuity is actually

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equivalent to an extremely nearsighted vision. With such a poor vision, it is impossible for someone to see the Great Wall even from 6 km of altitude, not to mention 300 km away from the Earth surface. In fact, 6 km of altitude is lower than the cruising altitude of most Jumbo Jets (8 to 10 km). People with flight experience know that one can see the Great Wall from airplanes in a clear sky. If Dai et al's six-minute theory were correct, a 1.5 m tall person would not be able to see a grain of rice on the ground. This obviously contradicts the reality.

Second of all, with an average width of 5 to 7 m, the Great Wall runs about 2400 km east to west from Shanhai Pass to Jiayu Pass. Snaking along hilltops, the Great Wall can hardly be perceived as a point object from space. Dai et al's analysis using visual acuity of point objects is erroneous and their conclusion is incorrect.

IV. THE GREAT WALL OF CHINA CAN BE SEEN FROM SPACE

The analysis should evidently be based on visual acuity of linear objects. A simple experiment may help us understand the difference between the visual acuity of point objects and linear objects. Put a small black dot of 0.1mm and a black line of 0.1mm width on a white background. Under the normal illumination condition, most people with 20/20 vision can see the dot at a distance up to 0.7 m and the line at a distance up to 10 m. The latter translates the visual acuity angle of linear objects into 0.034 minutes (eq. 1), much smaller than that of point objects. This is supported by evidences in a classic visual physiology book by Hugh Davson (Davson et al., 1990) in which the visual acuity angle of linear objects is said to be 0.5 seconds (or 0.0083 minutes). The smaller this angle is, the longer the distance is for one to still be able to see the object. It should be noted that this theoretical and experimental analysis assumes ideal environment conditions of clear sky, high visibility of the air, normal illumination, and normal physical conditions of observers.

From the above analysis, we can now find out the maximum altitude at which the Great Wall of China can be seen by naked eye. To be conservative, use 0.034 minutes as the visual acuity angle, 5 m as the width of the Great Wall. Rewrite equation (1) and use the above mentioned values, we get

$$D = 21{,}600L/2\alpha\pi = 505{,}807(\text{m}) \quad (2)$$

This demonstrates that the Great Wall of China can theoretically be seen at the altitude up to about 500 km. Considering that most manned spacecrafts are orbiting the Earth at a lower altitude of 160–320 km, it is logical to state that astronauts can see the Great Wall of China under ideal environment conditions.

V. FACTORS THAT AFFECTS THE GREAT WALL OF CHINA's VISIBILITY

Some factors may reduce the chance for astronauts to actually see the Great Wall. The short duration for spacecrafts to orbit over the area where the Great Wall is located limits the chance for astronauts to find the Great Wall. Visual physiology tells us that the maximum visual resolution is confined to a small area at the center of the retina (Latham et al., 1996). Away from the center area, the visual resolution declines quickly. Although we also have certain degrees of peripheral vision, objects can only be perceived clearly within the visual field of about 10 degrees of visual angle from the center of the eye. To positively identify an object on the ground from sky, one would need at least 12 seconds of time when he is mentally focused and actively moving his eyes in searching for the object (Boynton et al., 1958). If time is limited, or there are other mission duties on hand for distraction, the chance for astronauts to actually see the Great Wall is reduced.

In addition, weather conditions and seasonal variation also have significant influences in this matter. For example, leaves of deciduous trees fall in winter which reduces the color contrast between the Wall surface and its surrounding areas. This will inevitably cause the objects' visibility to decline (Regan et al., 1988) and thus make it difficult for un-trained eyes to differentiate them (Lulla, 2005). The occasional existence of local dust, air pollutants, and fog also lessens the likelihood for astronauts to see the Great Wall.

Furthermore, some objects on the ground such as dry river bed or roads in mountainous region resemble the linear shape of the Great Wall. Sometimes, even professionals would mistakenly classify other ground objects as the Great Wall (de Selding, 2005). If all of the above mentioned adverse elements exist at the time, the chance for astronauts to see and identify the Great Wall would diminish drastically.

However, there are other favorable conditions for astronauts to see the Great Wall. For example, the major proportion of the distance between spacecrafts and the Earth surface lies above troposphere and is virtually free of dust, pollutant, and fog etc. Such a super clear (relative to the visibility of the air in troposphere) air certainly favors the observation of the Great Wall from space.

The shade may also boost the chance of the actually observation. The Great Wall extends mostly east-westerly between 37° north and 41° north latitudes. The Sun, with an altitude of 30 to 70 degrees above the horizon (Christopherson, 2006), casts a shade on the north-side of the Great Wall. Use the Sun's average altitude angle of 45 degrees and an average height of the Great Wall of 7.5 m, the width of the shade is determined to be 7.5 m. Adding this shade width to the average width of the Great Wall (5 to 7 m on average) makes the Great Wall to be more visible from a distance.

VI. CONCLUSION

It is theoretically sound to state that under the normal physical

conditions, astronauts can see the Great Wall of China from space at an altitude lower than 500 km, provided that it is in the right season and the ground color contrast is maximal. Local air also needs to be clear and free of fog, dust, and pollution. Adverse conditions, such as the wrong season, lack of appropriate searching time, the existence of local fog, dust, or pollutants in troposphere and etc. may dampen the chance for astronauts to actually find and see the Great Wall. Unfamiliarity to the local geographic condition may also add difficulty for astronauts to positively identify the Great Wall and differentiate it from local dry riverbed and roads.

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