Development of Computer Vision System for Automation of Flat Mirror Solar Concentrator Assembly

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Abstract

Flat mirror solar concentrator permits us de decrease the cost and the weight of parabolic dish solar concentrators. Recently some types of flat mirror solar concentrators were developed. The design was complicated for its manufacturing and assembling automatization. In this article we propose new design of parabolic dish solar concentrator based on flat mirrors that can be easy manufactured and assembled. The problem of the assembly remains at the last step of the assembly process where the large number of flat mirrors must be placed and glued to the preassembled concentrator structure. To automate this step of assembly process we propose to use computer vision system based on neural classifier.

1. Introduction

One problem of image recognition appears when it is necessary to create automatic system for flat mirror solar concentrator assembly. Many different types of flat mirror solar concentrators were proposed [1], [2], [3], [4]. All of them need placement and fixture of large number of flat mirrors. For example, in the Australian concentrator [1] they used 2,300 square mirrors (100mmx100mm) for each concentrator. In our prototypes we used up to 210 triangular flat mirrors (Fig.1). To improve the characteristics of this concentrator we plan to increase this number up to 384 [3], [4].

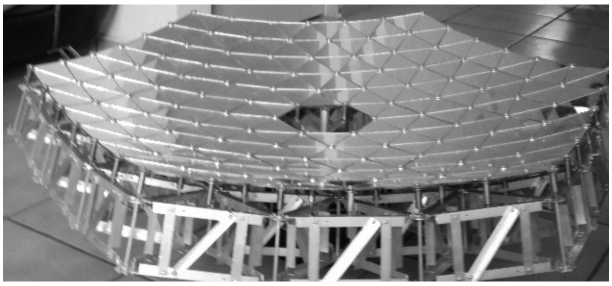

Figure1: Solar concentrator prototype with triangular flat mirrors

The prototype of solar concentrator with flat mirrors presented in Fig.1 was manually manufactured and position of mirror vertices were adjusted with special parabolic gauge in accordance with the patent [5]. This method of adjustment gives many advantages in comparison with other methods proposed for flat facet solar concentrators, for example [2].

The small flat mirrors must approximate the parabolic dish surface and the quality of this approximation depends on the number of small flat mirrors. So the problem of automatic mirror placement and fixture is important for solar concentrator production.

At present we initiate to develop the automatic system for manufacturing and assembly of flat mirror parabolic dish solar concentrators. At the beginning of this work we proposed to use a new design of support frame that is shown in Fig.2.

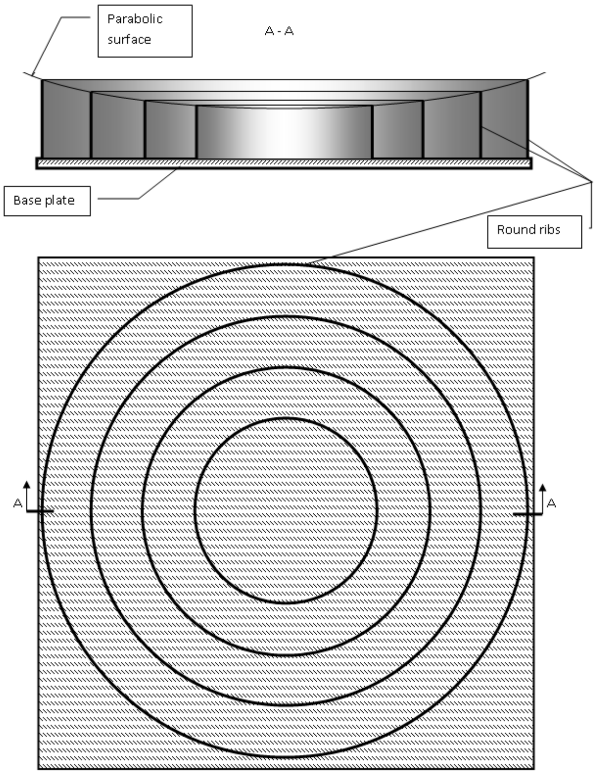

Figure 2: New support frame for flat mirror solar concentrator

This support frame contains the base plate, a number of round ribs that have different height that are glued to base plate concentrically. Their top lines form parabolic surface and serve to support flat mirrors that have in this case the trapezium shape (Fig.3) .

The flat mirrors are glued on the tops of round rips as is shown in Fig.3. To place each new flat mirror the automatic image recognition system has to evaluate three parameters:

1. displacement of mirror in *X* direction,
2. displacement of mirror in *Y* direction,
3. rotation of mirror around its center to the angle φ.

Robotic arm will be used to move mirror to the calculated position. The evaluation of three parameters (X, Y, φ) can be repeated during mirror movement to the target place. For solving of this problem we plan to use our experience in development of neural classifiers for pin-hole task [5].

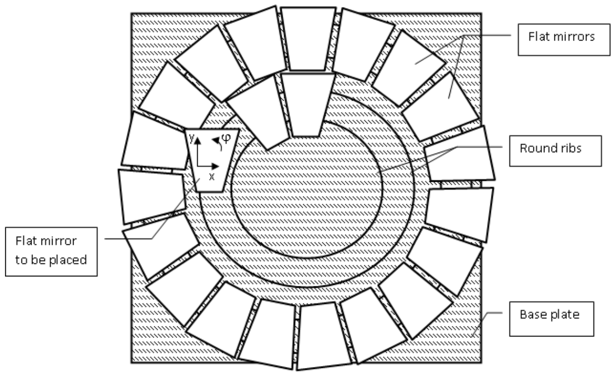

Figure 3: Scheme of flat mirror placement in new design of solar concentrator.

2. Pin-hole task

Earlier we have developed the computer vision system for pin to hole installation [6]. To solve this problem computer vision system must evaluate the displacement of the pin position relatively to the hole position. At that time the cameras were relatively expensive. For this reason we developed special plate (Fig.4) with four lamps that could be consecutively switched on.

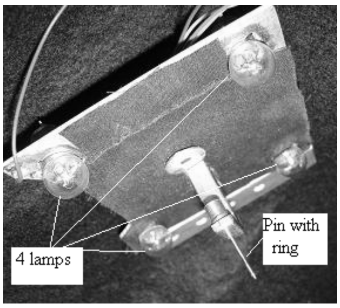

Figure4: Pin installation with lamps

It gave us the possibility to obtain four different shadows on the plane that contains hole. Using these shadows it is possible to evaluate two displacements Δx and Δy using only one web camera instead two web cameras that usually used for stereo vision. The experiments with this computer vision system had shown that the precision the displacement evaluation is approximately 0.1 mm. This precision is sufficient for new task of flat mirror placement in new design of solar concentrator.

3. Difference of mirror placement from pin-hole task

The first difference of the new task is the possibility of using two web cameras due to low cost. Because the web camera cost is approximately ten times less than ten years ago.

The second difference is that at present we need to evaluate three parameters instead of two.

In the previous project we created image database for neural classifier training. This database contained 441 images that correspond to different pin-hole displacements in matrix 21x21 pin positions and hole was situated in the center of this matrix.

To create similar image database for three parameters it is necessary 9261 images that corresponds to two displacements and one rotation. In this case the training time increase at least 21 times but the recognition time must increase only to the factor 1.5. So we hope that after the training this neural classifier may be effectively used for new task.

4. Error analysis

The problem of displacement and rotation recognition appears to be much easier if we will make the robust analysis of the errors of resulting optical system.

Let us consider the mirror installation manipulator (Fig.5) that has two degrees of freedom: one translational in *X* direction and the second – rotation of the gripper around its axis.

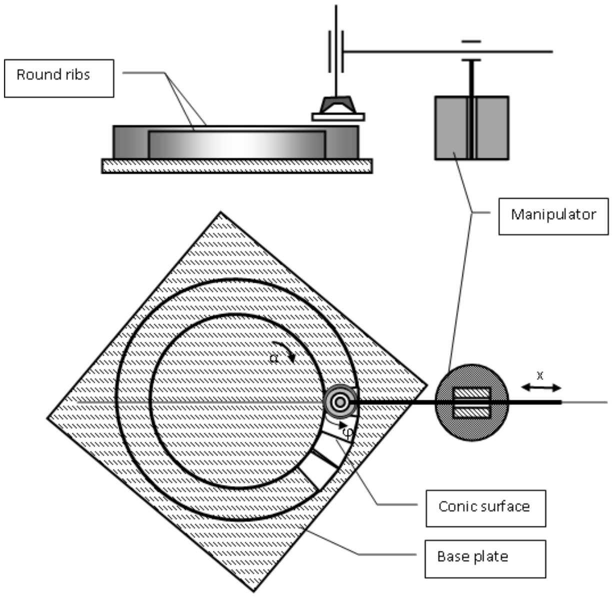

Figure 5: Mirror installation device

The third degree of freedom shown in the image (Fig.5) is used only to take new mirrors but not for installation it. The base plate can be rotated around its axis to arbitrary angle α. To place the next mirror the manipulator takes it from the depository and moves it to the placement position. The computer vision system adjusts its axis position and angle φ (Fig.5). After that the base plate is rotated for the angle that corresponds to the mirror width and manipulator moves the mirror down to setting it on the neighbor ribs.

The mirrors are placed on the neighbor ribs form the ring. These mirrors approximate conic surface. The angle of the cone is calculated to direct the light beam from the center point (center of gravity) of each mirror to the focal point of parabolic dish concentrator. It is clear that the error of rotation displacement $\Delta\alpha$ does not introduce the error of the center point projection to the focal plane of the concentrator. So, the problem of mirror positioning is reduced now to the two dimensional task. We think that the experience of the pin-hole task solving will be useful to solve the problem of flat mirror placement.

The concentrator design is shown schematically in Fig.2. It is clear that the height of the neighbor ribs that support the mirrors of one conic surface may be significantly reduced in the manner that the inner rib will have the same height for all ribs of the concentrator (for example, 3 mm). The height of neighbor external rib is calculated to obtain the projection of center point of each mirror coinciding with the focal point of concentrator. For the distance of 9 mm between the ribs, the height of the external ribs will be from 3 to 6 mm. The ribs for this concentrator can be made from tin plate or from thin aluminum sheat. This design will approximate not parabolic dish surface but so called Fresnel mirrors [7]. For this design the cost of metal material is very low. The main cost will introduce the base plate and the flat mirrors. The dimensions of modern photovoltaic concentrators have the order of magnitude of 200x200 – 500x500 mm^2. These dimensions permit us to make the base plate form the flat glass of 3mm thickness. The volumetric cost of flat glass is approximately 10 times less than the volumetric cost of carbon steel and 15 times less than aluminum. 3 mm flat glass costs now about 1.5 USD per square meter. The mirrors can have the thickness of 2 mm. The cost of these flat mirrors is now about 2 USD per square meter. So for this design the cost of materials is slightly more than 4 USD per square meter. Let it be 5 USD per square meter.

It is possible to use another support frame for flat mirrors of the parabolic dish concentrator. This support frame was proposed for Australian White Cliffs solar concentrators [1]. It was made as parabolic dish from epoxy fiberglass that had the thickness of 6 mm and diameter of 5 m. With this thickness the material for support frame is relatively expensive. Our estimation shows that at present this material may cost approximately 45 - 50 USD per square meter. It is clear that scaling down of this support frame must decrease the relative cost of the material because the volume of material decreases with the third power of scaling factor and the surface area decreases only with the power two of scaling factor. So if the concentrator has the diameter 0.5 m its thickness must be about 0.6 mm.

To test these parameters we made parabolic dish support frame from epoxy fiberglass of 230 mm diameter (Fig.6). We aggregated epoxy fiberglass layer by layer to obtain the rigidity of support frame that does not permit the deformations visible with eyes. As a result, we obtained the thickness of the support frame about 1 mm. This thickness is six times less than the thickness of Australian prototype.

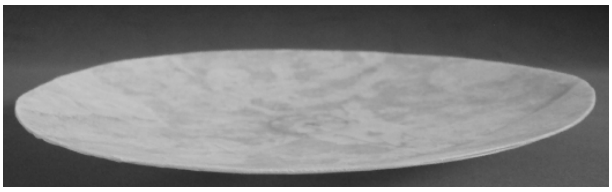

Figure 6: New support frame.

So for this prototype we evaluate the cost of the material equal to slightly more of 7 USD per square meter.

If we glue the 2 mm flat mirrors directly to the concave surface we can obtain of the total cost of material 7+2=9 USD per square meter. It is more expensive than the cost of materials of 5 USD per square meter for our first prototype. But probably it is possible to make this new design thinner because small flat mirrors glued on the concave surface increases the rigidity of the support frame. If the thickness can be made about 0.4 mm the cost of materials for both prototypes will be equal (Fig.2 and Fig.6). The second prototype (Fig.6) has many benefits from the point of view of flat mirror placement. Really, if the mirror has the trapezium shape it can be placed in each position of concave surface and its central point has the projection very close to the focal point of the concentrator. Very small error gives only the rotation of the mirror around its central point. This small error can be eliminated if we use triangular shape of flat mirrors. So, in this case the computer vision system must only provide the compact placement of triangular flat mirrors on the concave surface of support frame. This problem is much easier from the point of view of precision. We plan to develop and manufacture these prototypes and compare the parameters of the proposed versions.

5. Conclusions

Two types of flat facet parabolic dish concentrators were recently developed in Center of Applied Research and Technological Development of National Autonomous University of Mexico. The automatic placement of small flat mirrors on the parabolic dish surface of each prototype needs using of computer vision systems. Earlier we have developed the computer vision system to solve a pin-hole positioning task. This system can be adapted to solve the problems of automatic flat mirrors placement on the parabolic surfaces of new prototypes.

6. Acknowledgements

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7. References

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