REALISATION OF CIRCULAR MOTION FOR PORTABLE BTF MEASUREMENT INSTRUMENT

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Abstract - The paper contains analysis of possibilities for realization a large radius circular motion suitable for a portable measurement system for bidirectional texture functions (BTF) measurement. This circular motion will be used for changing the position of an array of detection cameras taking snapshots of sample illuminated by LED modules. The constrains for the proposed circular motion design are: large radius of motion about 300 mm limited to angular motion about 12°, non-accessibility of the centre of rotation which has to be kept free, total mass and price of the solution and motion deviation from centre point. We present three possible solutions comprising a single stiff curved guide with a ball roller, a curved guide with fixed rollers and two separated linear guides. We include an additional factor - the angular deviation of concentrically arranged array of cameras to evaluate the optimal solution reaching BTF measurement instrument needs.

Keywords: Bidirectional texture functions (BTF), portable instrument, measurement, circular motion.

1. Introduction

Bidirectional texture functions (BTF) measurement is one of the most important techniques in computer graphics how to process real appearance of surface textures. This technique is based on taking and analyzing a surface reflectance from a large number of snapshots taken under different combination of observer and illumination directions. Successful data processing necessary for high rendering quality needs thousands of surface images taken with high image resolution. Such process is time consuming and typically performed using stationary gantries [1, 2, 3] because of presence of expensive high resolution cameras, control systems and broad and precise mechanical motions. Such instruments are limited to measuring small samples or their fragments, but it is not possible to acquire data of large fixed samples or specimens which may change its pattern in time or when removed. There were developed few portable systems, which try to tackle such problems [4, 5, 6]. We recently successfully developed portable BTF measurement system based on single high resolution camera and kaleidoscopic imaging using multiple reflections within six mirror’s kaleidoscope [7, 8, 9]. Our next goal is to develop another system based on multiple low resolution cameras and to compare both data acquisition approaches. We want to cover all possible combinations of camera directions and illumination directions to eliminate data gaps in the rendering model.

This needs to make cameras movable with path length larger than cameras pitch distance. This paper is focused on possibilities of cameras circular motion realisation in case of portable system for BTF measurement.

2. Multiple Cameras System for BTF Measurement

Our new portable system for BTF measurement uses six cameras placed on meridian line and focused on the sample center. Based on optical computation including optimizing camera optic’s focal length and F-number, chip size, pixel size, camera-sample distance, depth of field and diffraction effects within the system we chose camera lens with FL=12.5 mm and Point Gray Flea3 USB3 Vision camera. We optimized the total distance between sample and camera chip to 253 mm. This distance originates from the dimensions of the whole portable measurement system. The system uses a PMMA hemispherical scaffold carrying 140 unevenly distributed high illumination LED modules. This scaffold with six cameras evenly separated by angle 12.7° can spin around the sample. Such design can deliver sample pattern data with any radial direction around the sample. Such design can deliver sample pattern data with any radial direction around the sample, but with only fixed six meridional angles. To overcome this drawback we decided to make cameras meridionally movable. Cameras motion is not necessary to be fully circular. Complete data can be achieved if the camera motion is larger than camera angular pitch distance. We tried to compare possible
solutions of such a motion with respect to our system demands.

3. Analysis Of Realisation Of Partially Circular Motion For Portable System

The aim of our work was to find the optimal solution for partially circular motion of the cameras in the meridional direction for our portable system for BTF measurement. We resolve a few conditions for motion system realization:

1. Minimum motion angle 12.5°
2. High stability of the motion – given by image pixel resolution
3. Low mass of the motion system
4. Low price of the motion system
5. Dimension of the whole system cannot exceed 600 mm in any direction

The demand of high motion stability and system stiffness leads us to use standard commercially available guides. Standard guides are produced as linear guides, but some producers offer curved guides too. The most limiting factor was the limited variety of available radii of curved guides. We found two kinds of commercially available curved guides: fixed roller curved guides (HepcoMotion) HDRT and recirculation balls curved guides (THK) R-guides. We select guides with the closest radius to our design and compare its properties. The data are summarized in two left columns of the Table 1.

<table>
<thead>
<tr>
<th>Producer / Guide type</th>
<th>THK HCR15A+60R/300R</th>
<th>HepcoMotion TR25 255</th>
<th>HIWIN MGN12R-0090</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available radius (mm)</td>
<td>300</td>
<td>255</td>
<td>any</td>
</tr>
<tr>
<td>Motion span (°)</td>
<td>60</td>
<td>90</td>
<td>13.5 (90 mm)</td>
</tr>
<tr>
<td>Static Permissible Moment Mc (Nm)</td>
<td>84.4</td>
<td>14</td>
<td>13.72</td>
</tr>
<tr>
<td>Roller dimensions (HxW) (mm)</td>
<td>24x47</td>
<td>30.5x80</td>
<td>13x27</td>
</tr>
<tr>
<td>Rail mass (g)</td>
<td>471</td>
<td>601</td>
<td>2x 34</td>
</tr>
<tr>
<td>Roller mass (g)</td>
<td>200</td>
<td>420</td>
<td>2x 58.5</td>
</tr>
<tr>
<td>Total mass (g)</td>
<td>671</td>
<td>1021</td>
<td>185</td>
</tr>
<tr>
<td>Total price (Eur)</td>
<td>702</td>
<td>672</td>
<td>67</td>
</tr>
</tbody>
</table>

Comparison of available circular guides shows that such a solution is pretty heavy and expensive. We prepared a sketch how the guides fit to our design, see Figure 1 and we found out that none of both curved guides is suitable for our portable system for BTF measurement. The THK HCR15A+60R/300R guide is too big and the overall dimensions of the measurement system would across maximal diameter 600 mm if we design it symmetrically.

The next smaller HTK HCR15A+60/150R curved guide with radius 150 mm is too small for our purpose.

The HepcoMotion TR25 255 curved guide is even heavier and it would be needed to extend the slot for camera’s motion within LED module scaffold almost two times to 72 mm to be able use it within our BTF measurement system. It would occupy the space for illumination LED modules and we would lose some combinations of illumination directions and camera directions for data processing. For this reason we were looking for another solution for partial circular motion realization for our portable BTF measurement system.

![Figure 1: Sketches of BTF measurement system with camera motion using HTK HCR15A+60/150R curved guide - left and HepcoMotion TR25 255 curved guide - right](image-url)
4. Realisation Of Partially Circular Motion Using Linear Guides

We focused on idea that we need only a segment of circular motion not greater than angle 13°. We decided to replace circular guide with two short straight guides. We performed numerical simulation of cameras motion for this design in Matlab software. We used two linear guides with effective path distance 60.6 mm placed under angles 4° and 67.5° from vertical axis. Results are shown in the Figure 2.

It shows the cameras perform almost circular motion around the centre. In reality optical axes of the cameras intersect the centre at single symmetric position. If we move cameras holder by the linear guides the intersection point of cameras axes moves away from the centre of the LED scaffold, as shown in the Figure 2 right. This intersection point motion is purely linear, because designed system behaves as Roberts mechanism, and maximal deviation of cameras intersection point from the centre point are Δx = - 1.30 mm and Δy = 1.81 mm. It will change cameras sample incidence angle. We evaluated maximal angular change for the most affected outer cameras for maximal motion out of the symmetry positions and results are presented in the Table 2.

These deviations are small enough to be easily software corrected during data processing. We were looking for optimal linear guide for such a motion realisation and we found HIWIN MGN12R linear guide with 90 mm long rail. Technical parameters of chosen linear guides can be compared with curved guides in Table 1.

This solution enables achieve good enough system functionality and mass and price reduction of our portable BTF measurement instrument. The sketch and 3D design of camera circular motion realized using two linear guides is shown in the Figure 3.

Table 2. Review of maximal cameras axis angular deviation from the sample centre point

<table>
<thead>
<tr>
<th>Dimensions in degrees</th>
<th>Left motion</th>
<th>Right motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left camera</td>
<td>0.3004</td>
<td>0.1781</td>
</tr>
<tr>
<td>Right camera</td>
<td>0.2071</td>
<td>0.2612</td>
</tr>
</tbody>
</table>

Figure 2: Simulation of cameras motion by two linear guides - left and detail of cameras axes intersection shift compared to centre position (blue mark) for symmetry arrangement. Scales are in mm.

Figure 3: Sketch and 3D model of BTF measurement system with camera motion using two linear guides HIWIN MGN12R-0090
5. Conclusions

We have analyzed technical possibilities for realization of partially circular motion of cameras for portable BTF measurement instrument. We searched for standard curved guides products and we evaluated technical and functional parameters of fixed roller curved guide HepcoMotion TR25 255 and recirculation balls curved guide HTK HCR15A+60/150R. We state these guides could be possibly used, but with negative effects on portable instrument design, increase of mass and price of the system. Finally we proposed another solution based on use two linear guides instead of curved guide for partially circular motion approximation. We chose HIWIN MGN12R linear guide with 90 mm long rail and we achieved good enough approximation of desired motion of the cameras. This design causes that intersection point of cameras axes deviated from original center point as cameras move out from the symmetry arrangement a little bit. We evaluated angular deviations of camera axis from original direction and the maximal error value 0.3° is achieved for maximal left position of the most left camera. These errors can be corrected during data processing for all cameras and position. We will test functionality of proposed solution soon as we finish its construction.

6. Acknowledgements

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7. References