Mirror Based Framework for Human Body Measurement

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Abstract - In the paper a camera-mirror based 3D measurement system is introduced aimed for reconstruction of human body parts. During the measurement the patient cannot maintain static state even for a short period which may negatively affect the accuracy of the reconstruction. Nevertheless by such applications the duration of measurement plays significant role, as well. In order to handle these issues synchronized camera group has been used together with two mirrors to capture the targeted object with a single shot entirely. As the results reflect the proposed approach might be suitable for many application where targets being in small motion must be measured at once.

Keywords - *Mirror, Camera, Measurement, Human Body, Single-shot.*

1. Introduction

The paper focuses on human body measurement based on stereo vision. There are a variety of methods developed for 3D shape measurement of the human body [1,2]. Among these methods the light section based ones are the most promising; however by utilizing such approaches the targeted surface must be static. Approaches belonging into this category are for instance the time of flight (TOF) based methods [3], multi-fringe projection techniques [4-6], laser stripe projection based solutions [7], etc. Although most of these methods are suitable for human body measurement, it should be noted that small motions, shaking, vibrations of the target must be considered and eliminated. For the measured person it is inconvenient or many times impossible to be static even for a while. Any type of motion may cause significant error in the measured data. Another issue is the environment where the measurement is performed. These are usually dark rooms (when considering light projection based methods) which is a source of further possible mental burden. In this study we have been focusing on passive measurement of human body parts by utilizing multiple synchronized cameras. Similar concept is used by motion capture techniques, however in that case only the motion of only few points (attached to the body) are tracked. Our primary goal was to extract the whole shape of the targeted surface from simultaneously captured set of images. Since the images are captured simultaneously the motion of the target does not affect the accuracy of measurement. In order to measure the target entirely usually multiple shots taken from different camera positions are needed. Such solutions however are not suitable if the target is in motion or is vibrating. By using many synchronized cameras surrounding the target the problem can be solved, however the price as well as the flexibility of such a system is not satisfactory. The number of cameras can significantly be reduced by using mirrors and specifically arranged cameras. Such an arrangement should ensure the visibility of the whole target by the cameras. This paper focuses on the development and analysis of such a mirror based system. During the experiments human leg parts have been considered as target.

The paper is organized as follows: In section II the basic concepts of the approach together with the used devices is shown. Section III deals with the flow of measurement including the system setup, calibration and accuracy verification, Section IV focuses on point correspondence problem and finally results and conclusions are reported.

2. The Basic Concept

During the experiments 4 cameras have been used to measure the targeted surface at designated circular marker points. The cameras have been synchronized by an external trigger input signal, thus allowing to measure moving or vibrating targets, as well. Since the primary aim of the research is related to human body measurement this consideration is important. Another consideration was to ensure the measurement of the whole object (such as leg, hand, etc.) based on a single shot. As already mentioned in the introduction measuring a target entirely needs usually multiple shots taken from different camera positions. The location of the camera can be determined based on feature matching or using some kind of active tracking system. Such solutions however are not suitable if the target is in motion or is vibrating. In such cases - depending on the frequency of vibrations - one-shot based solutions are more advantageous. An efficient alternative is to use many synchronized cameras surrounding the target, however the price as well as the flexibility of such a system is not satisfactory. A much cheaper and more flexible alternative is to use mirrors (in our experiment two planar mirrors) and a reduced number of cameras, where each pair of cameras is set to have short baseline. On one hand the short baseline promotes the correspondence matching however the quantitation error becomes larger. On the other hand by using more cameras (in our case 4 pieces) the increased quantization error caused due to short baseline can be compensated.

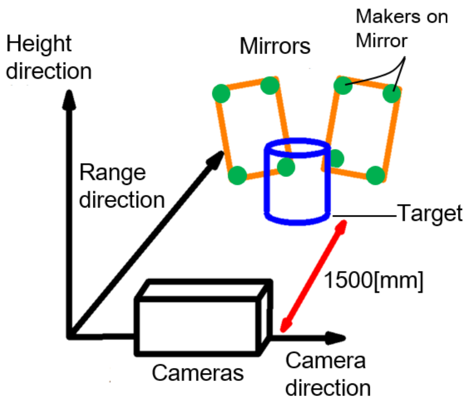

Fig. 1: Arrangement of components during the experiment

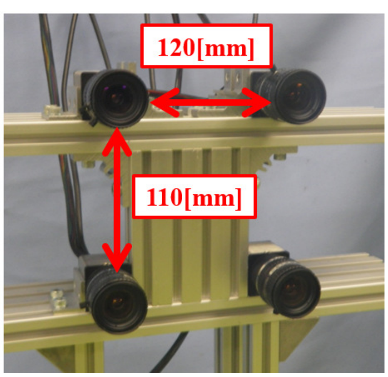

Fig. 2: Arrangement of cameras during the experiment

Table 1: Specification of devices used during experiments

Camera	IDS UI-3580CP-C-HQ, 4 sets Resolution: 2560 x 1920 [pixel]
Lens	Tokina KCM-0814MP, 4 sets
Slider	MiSUMi XLONG300-SB Accuracy: 150 [μm]
Mirror	OOKABE Co., Ltd Surface reflectance mirror

When mirrors are included into measurement system they can help to acquire the entire target at once however at the same time they stand for an additional error source. Namely, if the plane of the mirror is not accurately estimated the related error may have strong impact on the result. During the experiments we have paid high attention on these issues. Table 1 contains the specification of devices used during the experiment while Fig. 1 and 2 illustrate the arrangement of used components such as cameras, mirrors and the target. In the next section let us focus on the calibration related issues in more detail.

3. System Calibration

The proposed measurement system is composed of four cameras and two mirrors arranged as depicted by Fig. 2. First the cameras are calibrated by using direct linear transformation (DLT) or plane based calibration methods [8]. After the intrinsic and extrinsic parameters of each camera have been determined the plane of the mirror must be estimated with respect to a selected reference coordinate system.

During the calibration process, a calibration element depicted by Fig. 4 has been used consisting equidistant circular markers. The distance between adjacent markers was set to 80 mm in horizontal and 60 mm in vertical direction, while the radius of markers was set to 25 mm. In Fig. 3 the displacement of the calibration element, the mirrors and that of the camera group can be followed. The calibration element has been moved by linear slider to two known positions (let us denote them as **A** and **B**) at which the calibration was considered.

In order to validate the accuracy of the calibration the element has been placed between the positions **A** and **B** at which the spatial coordinates of markers have been determined by triangulation. The experiment has been carried out by two as well as by four cameras. The results can be followed in Table 2. Similar verification has been carried out by considering measurement across mirror. However in this case besides the error related to camera calibration, also the error related to the plane estimation of the mirror negatively affects the accuracy of reconstructed surface points. The achieved accuracy for both cases, i.e.

across mirror and directly without mirror can be followed in Table 2. When using four cameras a 50% increase in accuracy can be observed. The measurement trough mirror has caused relatively large decrease in accuracy however it is still in the range suitable for the planned application (~ 1 mm).

Let us now describe how the plane of the mirror is estimated with the help of the already calibrated cameras.

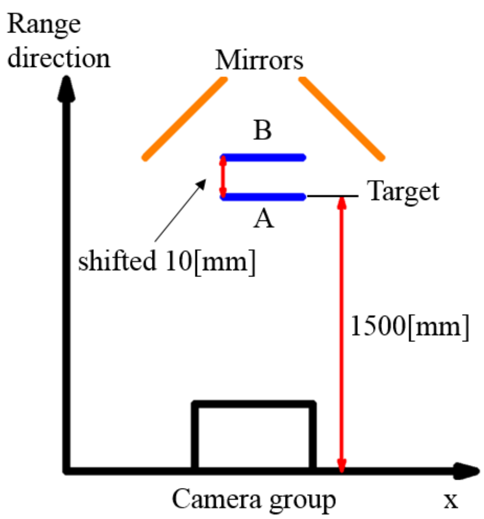

Fig. 3: Accuracy verification of the calibration

3.1 Mirror Plane Estimation

In order to estimate the plane of the mirror circular markers have be attached to it (see Fig. 5). By detecting their centers in the camera images followed by triangulation their spatial coordinates have been estimated and thus the equation of the plane formed by the mirror is obtained as follows:

$$\begin{bmatrix} x_1 & y_1 & z_1 & 1 \\ x_2 & y_2 & z_2 & 1 \\ \vdots & \vdots & \vdots & \vdots \\ x_n & y_n & z_n & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}, \qquad (1)$$

where x_i, y_i, z_i, i=1..n stand for the coordinates of marker centers in the world coordinate system and a, b, c, d stand for the coefficients of the mirror plane. We are searching for the least squares solution. After the plane has been determined the next step is to estimate the location of each virtual marker based on triangulation. Let us denote these points as $\mathbf{q}_i$. The coordinates of mirrored points $\mathbf{p}_i$ are determined across the estimated plane (see Fig. 6) as follows:

$$\begin{aligned} x_p &= as + x_q \\ y_p &= bs + y_q \\ z_p &= cs + z_q \end{aligned} \qquad (2)$$

$$s = -2\frac{ax_q + by_q + cz_q + d}{a^2 + b^2 + c^2}. \qquad (3)$$

Fig. 3 shows the arrangement of the system components, such as cameras and the mirrors together with the target. The distance between the camera group and the target was 1500 mm. The baseline in case of each camera pair was set to 120 mm.

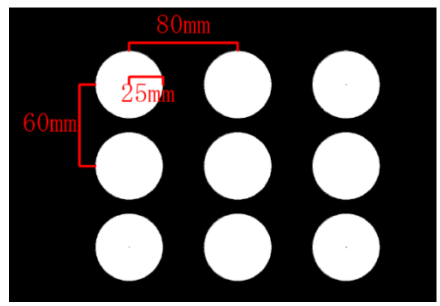

Fig. 4: Illustration of the calibration pattern

Table 2: Accuracy verification of the calibration

	by using two cameras		by using four cameras	
	directly	trough mirror	directly	trough mirror
Max. error	0.92	2.24	0.35	1.20
Min. error	0.25	0.68	0.15	0.52

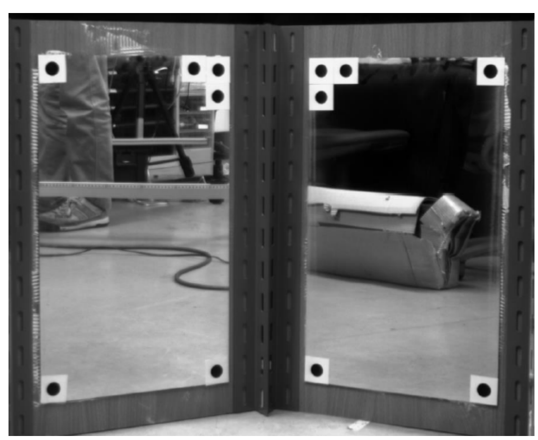

Fig. 5: Illustration of the arrangement of markers attached to mirrors

Fig. 6: The visibility of human leg parts in the mirror

4. Correspondence Matching

In order to estimate the spatial coordinates of a point by triangulation first the corresponding image points must be determined in the image plane of each camera. Let us denote the cameras as CAM_1, CAM_2,…,CAM_N, where CAM_1 represents the reference camera and N is the number of cameras. An incorrectly identified marker yields a line of sight which is relatively distant from the intersection point of the other lines (see Fig. 8). The number of considered markers is small since the baseline of each camera pair is set to be short from which it follows that the corresponding marker must be located relatively close to the reference marker [9].

The correspondence matching is performed in two steps, namely the pre-selection and the final selection step. During the pre-selection the shortest distance between the line of sight of the selected marker and that of its corresponding candidate is considered. If the shortest distance between the lines of sight is below a predefined threshold the candidate is further considered in the final selection. Since in each camera image there might be one or more markers fulfilling the above mentioned shortest Euclidean distance constraint, the final selection must yield one candidate (winner) for each camera. For this purpose let us define a cost function as follows:

$$C\left(\mathbf{p}_1,\mathbf{p}_2,\ldots,\mathbf{p}_{N-1}\right)=\sum_{i=1}^{N-1}\left\|\mathbf{p}_i-\boldsymbol{\mu}\right\|, \qquad (4)$$

where point $\mathbf{p}_i$ stand for the geometric mean of the closest points of two lines of sight corresponding to the selected marker in the image plane of CAM_1 and to a candidate in the image plane of $CAM_{(i+1)}$. N stands for the number of cameras, $\boldsymbol{\mu}$ the geometric mean of points $\mathbf{p}_i$. In the final selection those candidates are selected as winners which give the minimal cost C. The flow of the algorithm can be followed in Fig. 7.

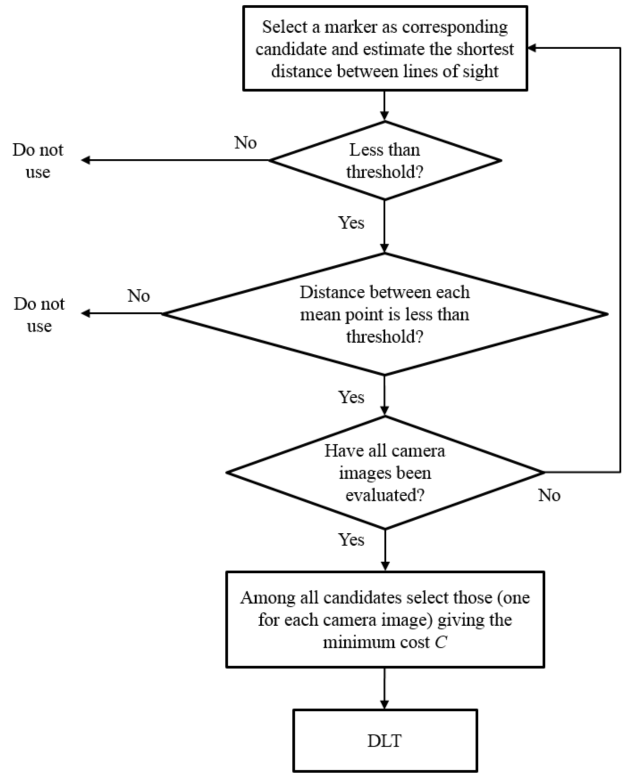

Fig. 7: The algorithm of the proposed correspondence matching

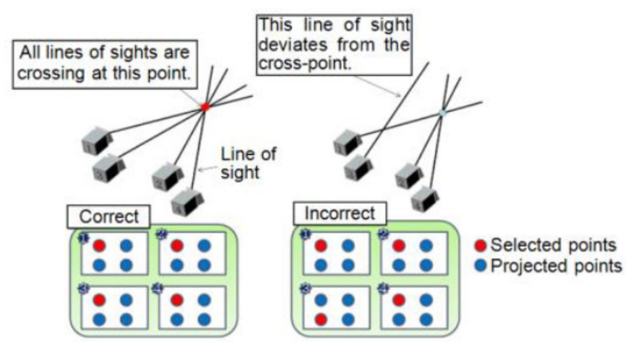

Fig. 8: Illustration of correctly and incorrectly identified markers and their lines of sight [5]

5. Results

In this section let us show the obtained results. As target a human leg has been selected (see Fig. 6). The result can be followed in Fig. 9 (red dots stand for the reconstructed markers).

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5.1 Accuracy Verification

In this experiment our main aim was to check the accuracy of reconstruction across the mirror. In this case as target a plate consisting markers with known arrangement has been used. The distance between markers was set to 40 mm. The radius of markers was set to 10 mm. The task was to compare the reconstructed distances (across the mirror) with the real values. In Table 3 the results of the experiment can be followed.

Table 3: Accuracy verification results

Minimum error [mm]	Maximum error [mm]
0.20	0.16

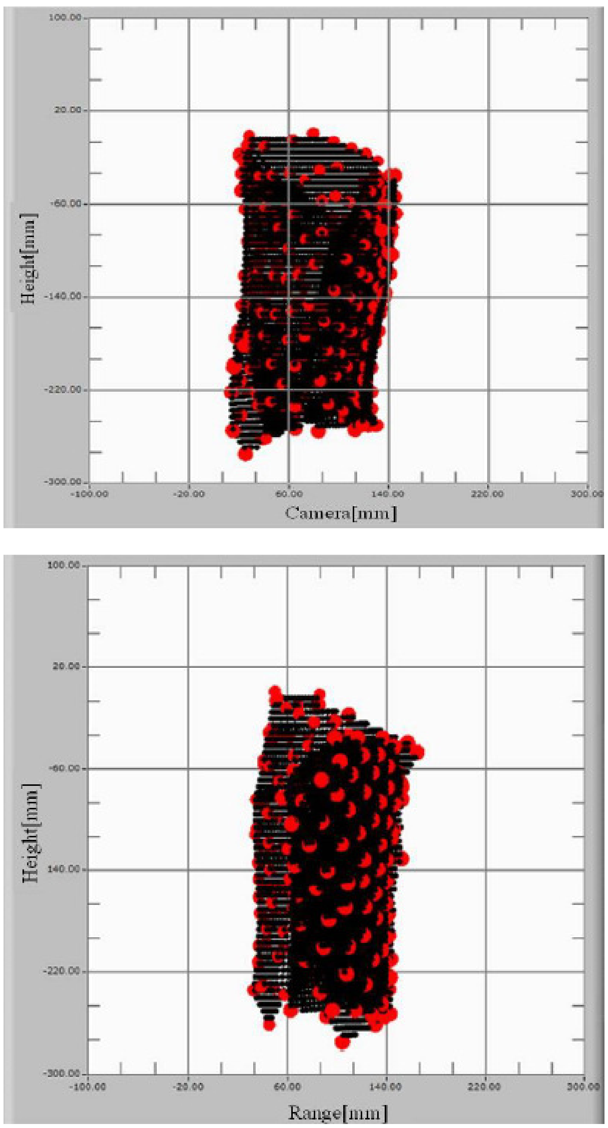

Fig. 9: Results of human leg measurement

5.2 Increasing the Density of Reconstructed Points

The density of markers can easily be increased by applying linear or nonlinear interpolation techniques. However due to the relatively low initial density of markers template matching based approaches are more promising. This is because in case of applying interpolation techniques many details located in between the measured markers cannot correctly be recovered. Since on the targeted surface the markers are distributed non-uniformly they can be used as good templates for correspondence matching. After the corresponding points have been estimated the spatial coordinates are obtained by triangulation. The similarity between two patterns has been determined by the normalized sum of squared differences (NSSD). The size of the window over which the pattern is evaluated plays also significant role, especially when there are repetitive patterns on the surface.

During the experiments the window size has been set according to the density of markers on the surface [10]. By using such an approach the details located in between the markers could also be recovered. The accuracy of the matching based reconstruction can be followed in Table 4. Similarly to the above mentioned cases the accuracy verification has been considered across the mirror and directly, as well. As the results reflect the measurement error is ~1 mm. In Fig. 10 and 11 the reconstructed markers together with additional points obtained by template matching based approach can be followed.

Table 4: Error of the template matching based reconstruction

	directly	trough mirror
Maximum error [mm]	0.34	1.02
Minimum error [mm]	0.13	0.56

6. Conclusions

In this paper a camera and mirror based measurement framework has been proposed for human body reconstruction. Since the cameras are synchronized the targeted surface should not be static which stands for the primary feature of this system. In addition, the mirrors (two planar mirrors in our case) together with the camera group ensure the acquisition of the entire target. The measured points are represented by markers attached to the targeted surface. Although their density is not high, it might be sufficient for many applications such as production of leg sleeves for example. On the other hand the density of reconstructed points can be increased by template matching effectively, thus widening the application possibilities.

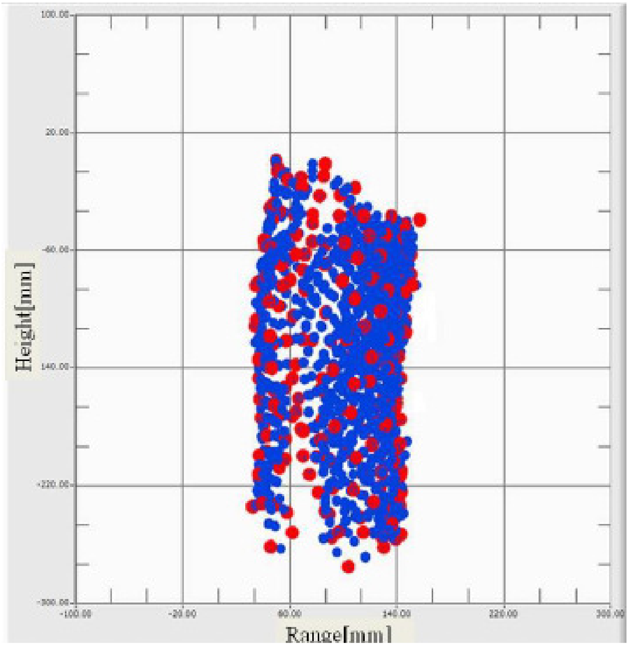

Fig.10: The reconstructed markers (red dots), by template matching (blue dots)

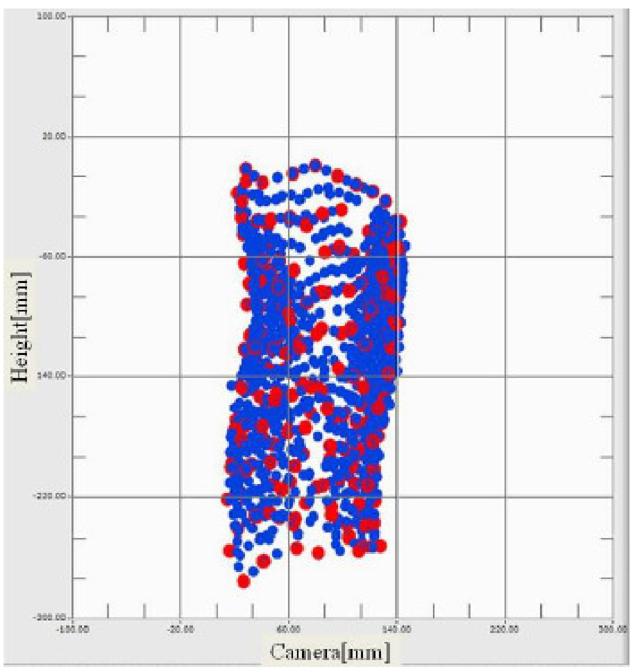

Fig. 11: The reconstructed markers (red dots), by template matching (blue dots)

References

[1] K. Yamauchi, Y. Sato, "3D Human Body Measurement by Multiple Range Images," *18th International Conference on Pattern Recognition*, vol. 4, pp. 833-836, 2006.

[2] P. Treleaven, J. Wells, "3D Body Scanning and Healthcare Applications", *Computer*, vol. 40, no. 7, pp. 28-34, July 2007.

[3] S. Yan Cui, Schuon, D. Chan, S. Thrun, C. Theobalt, ”3D Shape Scanning with a Time-of-Flight Camera,” *2010 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, pp. 1173-1180, 13-18 June 2010.

[4] N. Karpinsky, S. Zhang, ”High-Resolution, Real-Time 3D Imaging with Fringe Analysis,” *Journal of Real-Time Image Processing*, Springer-Verlag, Vol. 7, Issue 1, pp. 55-66, 2010.

[5] E. Lilienblum, B. Michaelis, ”Optical 3D Surface Reconstruction by a Multi-Period Phase Shift Method, *Journal of Computers*, Vol. 2, No. 2, pp. 73-83, 2007.

[6] M. A. Muquit, T. Shibahara, T. Aoki, ”A High-Accuracy Passive 3D Measurement System Using Phase-Based Image Matching,” *IEICE Transactions*, Vol. E89, No. 3, pp. 686–697, 2006.

[7] Hong-quan Xie; Hai-hu Jia, "The Development of 3D Laser Scanning Technique and Its Application in Land Reclamation," *2nd International Symposium on Information Engineering and Electronic Commerce (IEEC)*, pp.1-4, 23-25 July 2010.

[8] Z. Zhang, “A flexible new technique for camera calibration”, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 22(11):1330–1334, 2000.

[9] T. Hashimoto, T. Suzuki, H. Aoshima, A. Rövid, ”Multi-Camera-based High Precision Measurement Approach for Surface Acquisition,” *Acta Polytechnica Hungarica*, Vol. 10, No. 8, pp. 139-152, 2013.

[10] T. Hashimoto, S. Takayanagi, A. Rövid, ”Correspondence Matching for Stereo Vision Based Outdoor Measurement,” *International Symposium on Flexible Automation*, Awaji-Island, Hyogo, Japan, 14 - 16 July, 2014, pp. 1-3.