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TECHNOLOGY OF NON-CONTACT MEASUREMENT OF AUTOMOBILE GAP FOR SEMI-AUTOMATIC USE

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Abstract. *The paper represents infrared laser and digital camera based equipment for measurement of gap and flushness on the automobile. The system is based on smartphone that is used as camera and database, while the red laser is targeted as measurement tool. The method used to measure the gap and flushness is based on laser triangulation. The camera on the smartphone captures the laser line projected on the body of the automobile and serves as database of captured photos. The measurement algorithm is done on remote computer based algorithm that serves as computation station for gap and flushness measurement. Experiments are done on real car body in laboratory conditions. The process is done as effective replacement of operator's gap and flushness measurement in the production process. The results enable to eliminate the operators' error and help to implement semi-automatic measurement system in theproduction plan.*

Keywords: *non-contact measurement equipment, laser triangulation, gap and flushness, smartphone camera, database, high-resolution picture, curve fitting, circle fitting, Industrial Internet of things (IIoT).*

КОНТАКТСИЗ ЎЛЧОВ ТЕХНОЛОГИЯСИНИНГ АВТОМОБИЛЛАР УЛАНУВЧИ ҚИСМЛАРИ ОРАЛИҚ МАСОФАСИНИ ЯРИМ АВТОМАТИК ТИЗИМИ ПРОЦЕССИДА ҚЎЛЛАШ

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Аннотация. *Ушбу мақола инфрақизил лазер ва рақамли камера асосида автомобиль кузовидаги оралиқ масофаларни ўлчаш ускунасидан фойдаланиш таҳлилига бағишланган. Тизимнинг ажралмас қисми смартфон бўлиб, у камера ва маълумотлар базаси, инфрақизил лазер эса ўлчов воситаси сифатида ишлатилади. Оралиқ масофани ўлчаш усули лазер триангуляциясига асосланган. Смартфондаги камера автомобиль кузовига йўналтирилган лазер линиясини расмга олади ва рақамли фильтрлардан ўтказади. Ҳисоб-китоблар махсус алгоритм асосида хизмат қилувчи компьютерда бажарилади. Тажрибалар лаборатория шароитида ҳақиқий автомобил кузовида олиб борилди. Ушбу технология ишлаб чиқариш жараёнида қўлда операторлар томонидан ўлчаш учун самарали аналог сифатида ишлай олади. Олинган натижалар инсон омилини бартараф этиш ва ишлаб чиқариш жараёнида ярим автоматик ўлчаш тизимини амалга оширишга ёрдам беради.*

Калит сўзлар: *контактсиз ўлчов ускуналари, лазер триангуляцияси, оралиқ масофа, смартфон камераси, маълумотлар базаси, юқори аниқликдаги тасвир, чизиқни мослаш, доирани мослаш, Саноатдаги Интернет Нарсалари (СИН).*

ПРИМЕНЕНИЕ БЕСКОНТАКТНОГО ИЗМЕРИТЕЛЬНОГО ПРИБОРА ДЛЯ ИСПОЛЬЗОВАНИЯ В ПОЛУАВТОМАТИЧЕСКОМ РЕЖИМЕ

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Аннотация. *Данная статья рассматривает применение бесконтактного оборудования на основе инфракрасного лазера и цифровой фотокамеры для измерения зазора на кузове автомобиля. Составной частью системы является смартфон, который используется в качестве камеры и базы данных, в то время как инфракрасный лазер – в качестве измерительного инструмента. Метод, используемый для измерения зазора, основан на лазерной триангуляции. Камера на смартфоне фиксирует лазерную линию, проецируемую на кузов автомобиля. Алгоритм измерения выполняется на удаленном компьютере, который служит вычислительной станцией для измерения зазора и промывки. Эксперименты проводятся на реальном кузове автомобиля в лабораторных условиях. Этот процесс является эффективной заменой ручного измерения зазора в производственном процессе. Полученные результаты позволяют исключить ошибки операторов и помогают внедрить полуавтоматическую измерительную систему в производственный процесс.*

Ключевые слова: *бесконтактное измерительное оборудование, лазерная триангуляция, зазор, камера смартфона, база данных, изображение высокого разрешения, подгонка кривой, подгонка круга, промышленный Интернет вещей (ПИВ).*

Introduction

Competition among car producers and diversification of production processes triggers the companies to make special attention on the quality of the vehicles produced. The quality control system in automobile production process has a number of different test processes that help to comply with standards of car makers. Gap and flushness (G & F) measurement is on the important stage in the quality inspection process in automobile production plant.

G&F is a difference between adjacent car bodies panels where flushness is the difference between the surfaces of panel aligned with normal vectors, while the gap is parallel difference [1]. Defects resulting from G&F create bad insulation between adjacent car body panels, water leakage, annoying noise and vortex that lower aerodynamic drag coefficient of vehicle. Identification of the defect at any stage of production enables to rip the chain of defect part making at that point.

1.1. Actuality of the issue

The thesis mainly emphasizes the automobile industry in Uzbekistan, namely JV “UzAutomotors”. Global competition among the car manufacturers around the world triggers local car manufacturer to pay more attention on the vehicle quality and client-satisfaction level. The government decrees, policy of local vehicle part production and broadening the market of local car manufacturer implies delving into development of modern quality control and inspection methods.

Digital factories play a key role in the digitalized economy that is the main priority nowadays policy. However, digitalization of the production processes around the world still a big issue in countries where the human labor cost is low.The era of Industry 4.0 is coming with a big leap in these countries that makes more problematic to integrate them into globalmarket. According to the Industry 4.0, zero-defect manufacturing (ZDM) is the basement of automated digital factories. ZDM has its own standard one of which is that the analysis of the data at the quality control stage should be monitored and stored.

1.2. The gap and flushness measurement

The problem of the inspection process of G&F is one of the research issues in the automobile industry. Depending on the automation level of the factory, the gap and flushness is measured in different ways. Local car manufacturer uses a manual method of measuring G&F, the process is done manually with special gauges as in figure 1. These gauges are being used by the operator to measure the G&F visually directly on the body of the car.

Operators still taking measurements by feeler gauges and dial gauges, resulting in a high number of operator’s error and as a result on defect part production. Also, the process is time-consuming and there is no data available to monitor further the result and drawbacks. There is also a cost to store the measurement results by hand in the database.

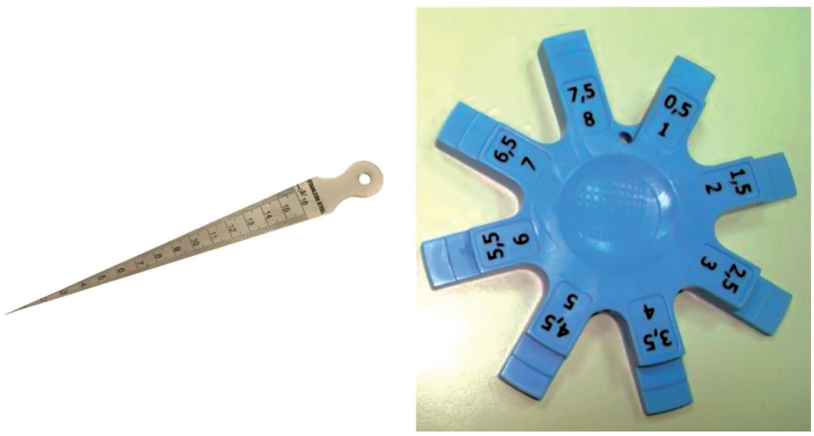

Figure 1. Gap and flushness measurement gauge used by operators for inspection of the body in white and finished product

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While the companies are trying to cope with the problem of time, quality and cost, the G&F is still pulling backwards each of them. Zero defect manufacturing (ZDM) is a key part of digitalization of the factory that should comply in order to target Industry 4.0.

In particular, an important aspect of ZDM is 100% in-line quality control of production. In the automobile production systems where the process a number of steps before the finished product is manufactured, the earlier the defect is detected the better. [2, 3, 4] Early defect inspection prevents from the propagation of defect downstream. The quality inspection process is the list of procedures to make a decision whether a part complies with the standards. In this process, measurement uncertainty plays an important role. When the data is uncertain the result cannot be certain [5, 6].

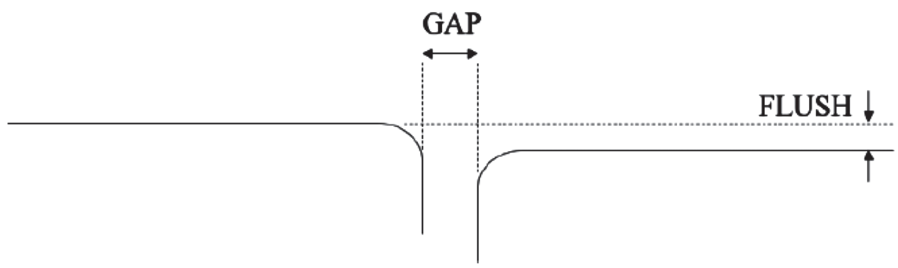


Figure 2. Gap and Flush definition – taken from Minnetti et al.*

*[7].

In the countries where the human labor cost is low, the need for automation is not a big deal. However, even the automation level is high, the operators still can play an important role. In fact, for the purpose of multitasking and solving technical issues, humans, are often in charge of complex multitasking.

This paper suggests a new measurement equipment for G & F inspection process as semi-automated method to be used by operators that is connected to factory database, integrating Industry 4.0 even with the interaction of operator. In addition, the approach is industrial Internet of things (IIoT) based methodology.

1.3. The state of scientific works done on the issue

The measurement of G & F can be done automatically in the different stages of automation depending on the level of automation of the factory, using stationary measurement systems as in [7, 8, 9]. T.-T. Tran and C. Ha used a high resolution camera and a multi-line laser generator that is used to project on to surface of the vehicle until it is in visible region. This system has a big advantage with speed and electronic circuitry makes the system respond quickly, but the drawback is their cost and usage with industrial robotic systems. So, in some areas in production, they are not implemented and operators still follow manual measurement process. Also, another commercial available product is able to follow G&F inspection standard using markers on the object that makes the process complicated [10]. T. Pribanic, T. Petkovic, M. Donlic, V. Angladon and S. Gasparini, turned a smartphone into IR projector using random dots and made structured line scanning. However, the system was designed specifically for the Samsung Galaxy Beam (which includes camera and small projector) [11]. Laser-triangulation based devices has been used in the market as commercially available devices such as GapGunPro [12], LMI Laser Gauge [13], and In-sight Laser Profiler [14]. However, these commercially available devices have a quite complicated systems to be used by operators and too many other functionalities that are not required. Also, the price is the other big issue in these devices. E. Minnetti et al used a smartphone, Time of Flight sensor, PiCam camera, Raspberry Pi Zero and laser line with a wavelength of 405 nm projected onto the body. Raspberry Pi is used as a processing unit, while smartphone just a method to transfer data [15]. Therefore, the aim of the paper is to develop a system to measure the G & F that is cost-effective and operator-friendly.

2. Materials and Methods

2.1. Methods used in our system

Based on the issues of the systems already implemented by different researches, a new system is described in this paper. It is also a smartphone-based system [13], whuch controversially uses laser triangulation method with a smartphone as camera and database. The main focus of the G&F measurement system is following:

1. Measurement system uses a red line laser projector and smartphone camera to capture the images of the laser on the body of the car. Also, the smartphone is used to store that data and afterwards to upload it to the cloud.
2. The cloud is Matlab based cloud that is automatically connects with PC based Matlab algorithm to work with captured images. The software algorithm is based on filtering the laser image into the binary image and extracting the line. The line is extracted based on the mean value of the thickness of the line.
3. Then the algorithm of Taubin for circle fitting is used to find the radius of the curvature of the edge points of the gap.
4. The camera is calibrated with known parameters of the gap and flushness in the car.
5. The principle of usage in the production line is portable and handheld.

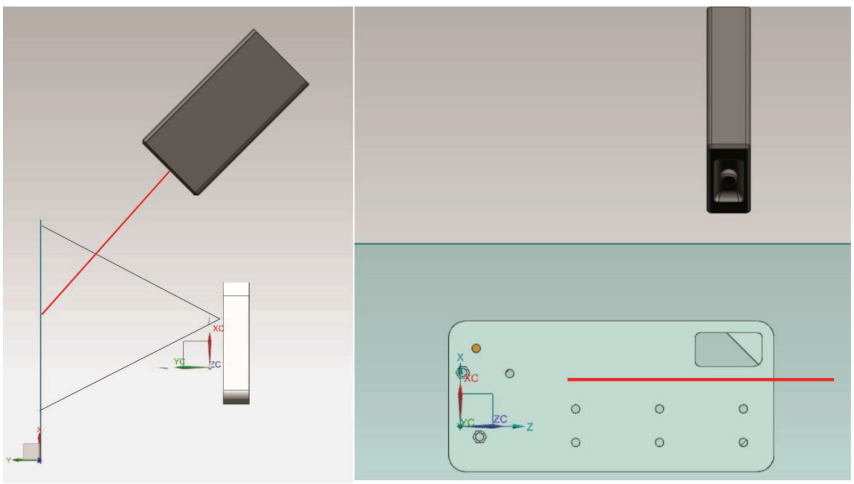
The importance of our approach is that it uses the simple smartphone and laser triangulation for measuring the G&F. The novelty of the approach is that it uses a new method for using a semi-automated process.

2.2. G & F measurement structure

The gap and flushness measurement system consists of the smartphone, laser module and battery switch system. The system is portable in order to give more redundancy to the operator and apply a semi-automated process as a small part of zero-defect manufacturing. The system has a storage capacity that makes it analyzable to the issues.

Measuring target specifications are the body part of the Nexia 2 model of GM Uzbekistan is considered what has a grey color in the Mechatronics laboratory of Turin Polytechnic University in Tashkent. The body of the vehicle was brought after the painting shop in Uzautomors.

The measurement is done by hand moving from one G & F measurement point to the other one. The working principle is shown in figure 2.

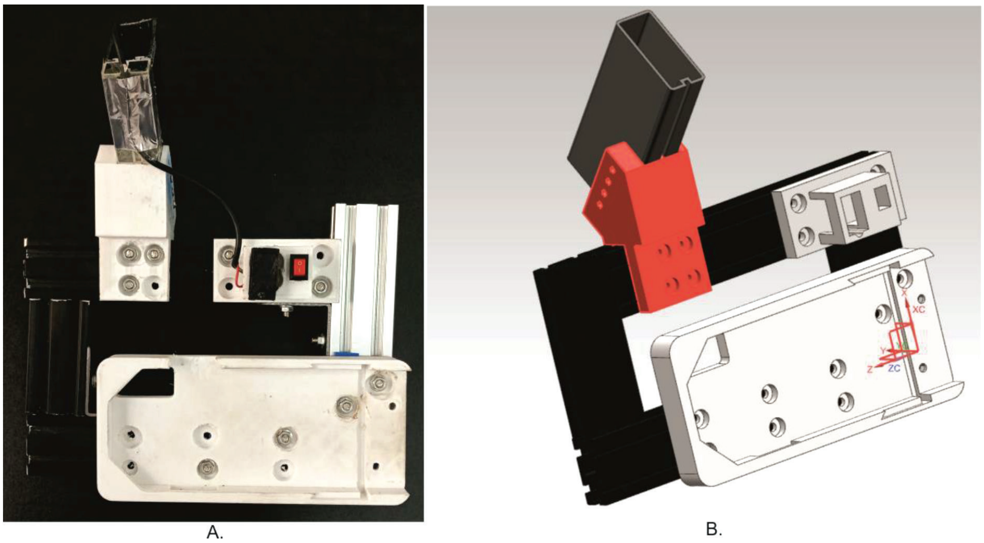


A. B.

Figure 3. Working principle of laser triangulation a) front view and b) left view

Laser light reflection on the body of the car is another issue as the light is always reflected on different surface differently. The camera sensor might capture the light with a different noise. One possible solution is to use the laser with short wavelength. The project uses the red laser with wavelength of 650nm and power of 5mW that is powered by 4.5V batteries.

The research uses budget Samsung Galaxy A10s smartphone in order to capture the laser line and store it in Matlab Cloud. The camera is with 13 megapixel CMOS sensor (rear camera) with f1.8 and f 2.4. Figure 3 shows the real model and the 3D CAD model of the measurement instrument. The laser is organized in the way that it is projected onto the object under 45 degrees.



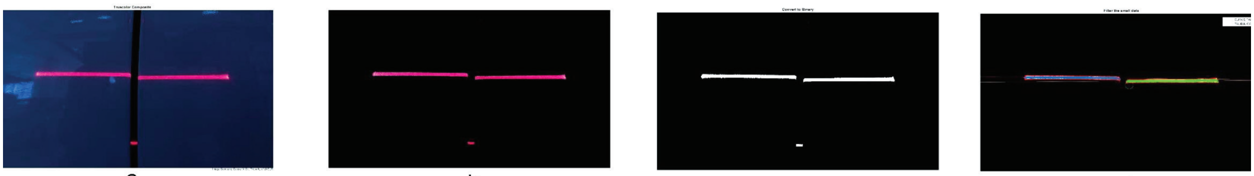
A. B.

Figure 4. a) prototypemodel b) 3D CAD model

The method used to measure is based on image processing algorithms. Operator fixes the position of measurement of G&F. Then operator captures the phone camera with predefined smartphone camera settings for optimal capture. The captured image automatically uploaded to Matlab cloud through internet and the data is transferred to PC. The software is a matlab based script algorithm that first uses the image processing toolbox inside the Matlab to extract the red light in the RGB image. Then the image is binarized to extract the consolidated data of two laser lines. The contours are extracted afterwards using the CoMP algorithm. Extremeties are then extracted from the two contours. Gaussian fit is applied to the extracted contouring in order to give the sub-pixel accuracy. The database is used to record a history of all the measurement records.

Laser profile extraction is done based on the binary image data and positioning the mean of the consolidated laser data.

The red line is extracted from the RGB image and then binarized. Then the small dots and noises are filtered in order to have clean data. The blobs of pixels have a number of pixels smaller than 10000 pixels. Figure 4 represents the algorithm of extraction of the data from the raw color picture.



a b c d

Figure 5. Image processing algorithm a) row color data b) extracted red c) binarized d) filtering and fitting is applied

The center line of the contour is found by simply applying the mean value for column varying the rows. Based on the equation 1 the center line is found from the contour. Considering c as a column and r as a row we can find the center for binary pixels.

$$mean = \frac{\sum_c^r I}{\#number\ of\ white\ pixels\ in\ column}; \quad (1)$$

Each mean from the data is saved and denoted as the contour line as in figure 5.

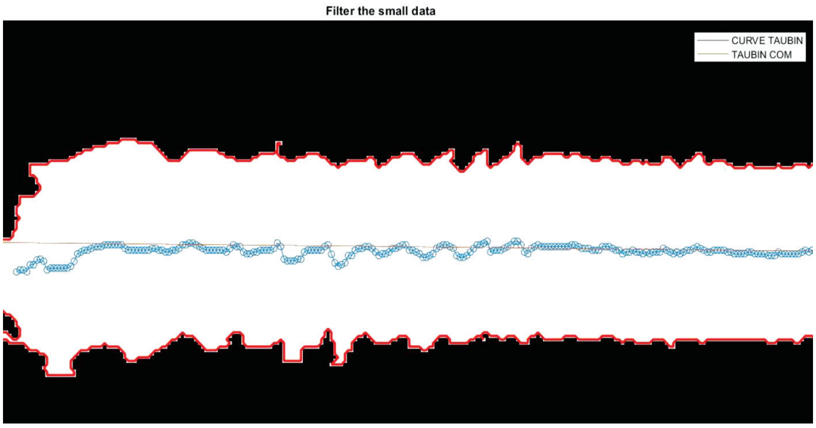


Figure 6. The middle line as the center for caption laser line

The data is analyzed and line is fitted as linear regression method to make best-fit line to measure the flushness. The data is then fitted to find the curvature at the end of the contour as the sheet is always circle at the edges. The method to circle fit is the Taubin circle fitting method.

$$A(x^2 + y^2) + Bx + Cy + D = 0 \quad (2)$$

$$F = \frac{1}{4*R^2} * F_t \quad (3)$$

$$F_t = \frac{\sum_{i=1}^{n}[(x_i-a)^2+(y_i-b)^2-R^2]^2}{4n^{-1}\sum_{i=1}^{n}[(x_i-a)^2+(y_i-b)^2]} \quad (4)$$

The fitting method can be seen in the figure 6. The edges of the laser to get the gap and flushness.

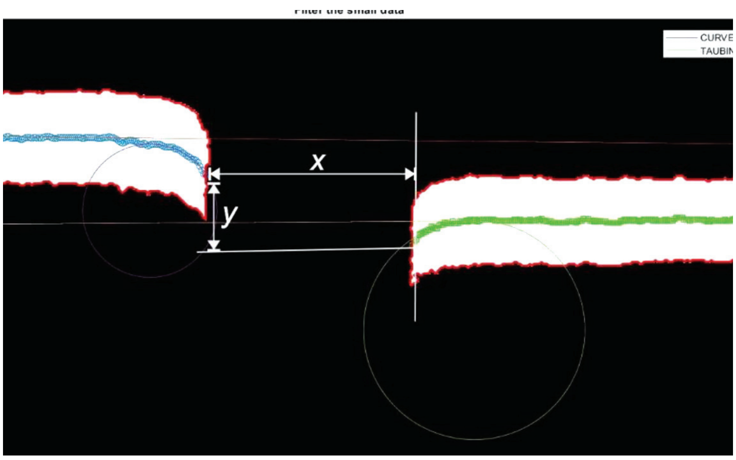


Figure 7. The circle fitting method by Taubin and the difference of pixels in the filtered data x and y

The gap and flushness are measured by the method that is used in the production line by operators. The gap is defined as horizontal difference between the circles while the flushness is the vertical.

The calibration is done on the direct artifact and measured with calibrated caliper. The artifact is the laboratory based vehicle in figure 7. known as Nexia 2 GM Uzbekistan product.

Figure 8. The model for using the gap and flushness as calibration artefact

3.1. Experimental methods defining gap and flushness measurement

The method to measure real data from RGB image is based on the calibration of the device. The direct calibration is considered [16] based on the model approach [17]. Direct calibration is done with artefact that is vehicle in the laboratory used as an ideal model to measure. The G&F is measured on the basis of the equation 5,

$$g = C * I \qquad (5)$$

where g is the gap and flushness measurement in the mm while I is the value of gap and flushness in image pixel, C is the calibration matrix.

$$C = \begin{bmatrix} G \\ F \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 1 & \frac{1}{tan\alpha} \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \qquad (6)$$

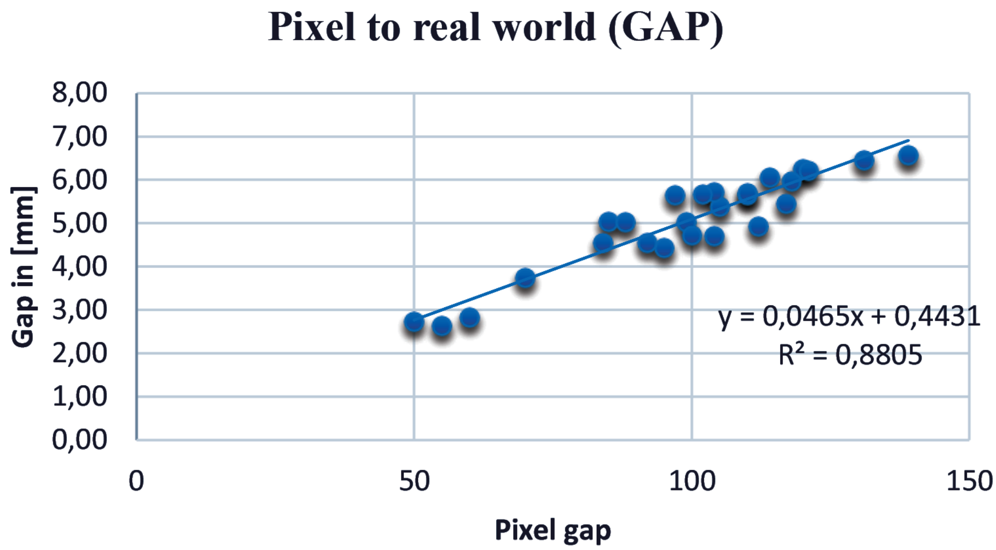
x is the horizontal difference between the edges and y is the vertical difference as in figure 6. Finally the measurement is taken and filtered data is used to measure the real G&F in the real world.

Calibration is done in order to find the G&F on the vehicle itself. The pixel to real world conversion is necessary in order to complete the measurement and equation 6. The I is the matrix consisting of the calibration parameters for gap and flushness I = [Ig; If]. A direct calibration is performed with the laboratory vehicle as artifact with 25 measurement points. The gap values range from 1-5 mm and the flush has a range of from 0.2-2.2 mm. These two ranges satisfy the range standard for production process in UzAutomotors. The relation model of pixel to real world is shown in figure 8.

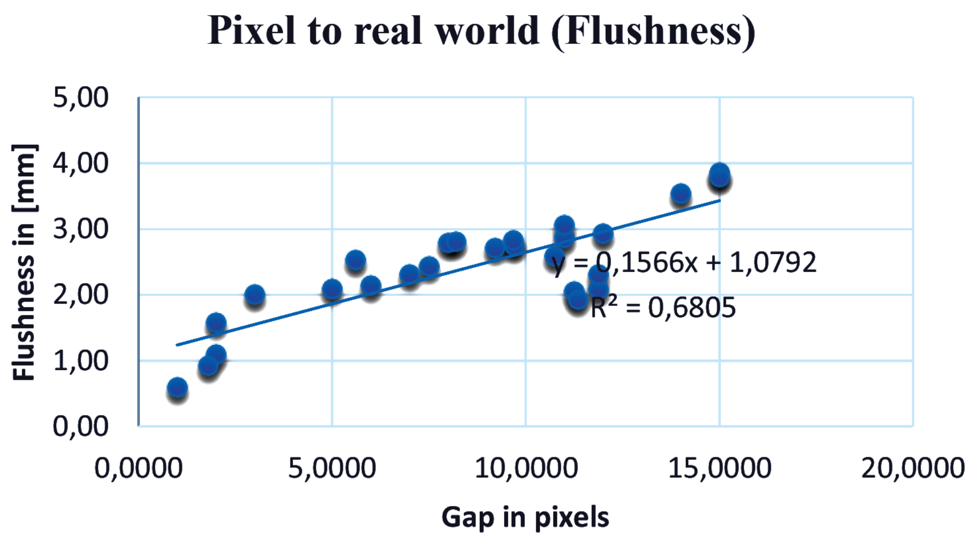
Ordinary linear regression is applied to the data in order to find the real world data. The linear regression shows a good fit on the data. The system is checked with the operator handling the device not only on the fixture but directly on hand in order not to have problem further with mismatch of data.

3.2. Experiment results on real car

The hand-held device was used inside the university laboratory to test the methodology. The actual production line is the motion production process with different color system and difference in operators usage, that may affect the measurement uncertainty of the device.



a.



b.

Figure 9. The calibration data for gap and flushness: a) gap conversion b) flushness conversion

A manual caliper with the uncertainty of 0.01mm is used as measurement checking device.

Repeatability and Reproducibility uncertainty was estimated for the device. Repeatability is estimated by making a series of measurement by the same person under the same measurement conditions. Reproducibility is estimated by makinga series of measurements, each by a different person. The method of determining both repeatability and reproducibility in a single test is a Gage Repeatability and Reproducibility (Gage R&R) Analysis of Variance (ANOVA).

Temperature may also affect the data on uncertainty of the G&F in terms of the thermal expansion.The change of the part when exposed to the temperature is a natural process that introduces uncertainty in to the measurement. That is why the temperature indoors is used based on [18], the level of exposure on temperature was from 20 to 27 ^{o}C. The temperature compensation is also included in uncertainty measurements.

Table

	Gap measurement							Flushness measurement					
	Pixel	Mea-sured	Nominal	Offset	Standard deviation	Standard error		Pixel	Measured [mm]	Nominal	Offset	Standard deviation	Standard error
1	104.0000	5.2791	4.7000	0.5791	3.3072	0.6614	1	11.8700	2.9380	2.0867	0.8514	0.6020	0.1204
2	99.0000	5.0466	5.0233	0.0233	0.0165	0.0033	2	8.0000	2.3320	2.7900	-0.4580	0.3239	0.0648
3	100.0000	5.0931	4.7167	0.3764	0.2662	0.0532	3	10.7424	2.7615	2.5867	0.1748	0.1236	0.0247
4	95.0000	4.8606	4.4300	0.4306	0.3045	0.0609	4	6.0000	2.0188	2.1467	-0.1279	0.0904	0.0181
5	92.0000	4.7211	4.5500	0.1711	0.1210	0.0242	5	7.5000	2.2537	2.4367	-0.1830	0.1294	0.0259
6	112.0000	5.6511	4.9233	0.7278	0.5146	0.1029	6	9.7000	2.5982	2.7467	-0.1484	0.1050	0.0210
7	117.0000	5.8836	5.4500	0.4336	0.3066	0.0613	7	7.0000	2.1754	2.3100	-0.1346	0.0952	0.0190
8	105.0000	5.3256	5.3833	-0.0577	0.0408	0.0082	8	5.0000	1.8622	2.0933	-0.2311	0.1634	0.0327
9	110.0000	5.5581	5.6467	-0.0886	0.0626	0.0125	9	11.0000	2.8018	2.8700	-0.0682	0.0482	0.0096
10	97.0000	4.9536	5.6433	-0.6897	0.4877	0.0975	10	12.0000	2.9584	2.9333	0.0251	0.0177	0.0035
11	104.0000	5.2791	5.7100	-0.4309	0.3047	0.0609	11	11.2500	2.8410	2.0500	0.7910	0.5593	0.1119
12	110.0000	5.5581	5.6900	-0.1319	0.0933	0.0187	12	2.0000	1.3924	1.5833	-0.1909	0.1350	0.0270
13	102.0000	5.1861	5.6600	-0.4739	0.3351	0.0670	13	3.0000	1.5490	2.0067	-0.4577	0.3236	0.0647
14	85.0000	4.3956	5.0333	-0.6377	0.4509	0.0902	14	2.0000	1.3924	1.0967	0.2957	0.2091	0.0418
15	88.0000	4.5351	5.0200	-0.4849	0.3429	0.0686	15	1.8000	1.3611	0.9300	0.4311	0.3048	0.0610
16	84.0000	4.3491	4.5433	-0.1942	0.1373	0.0275	16	1.0000	1.2358	0.6000	0.6358	0.4496	0.0899
17	114.0000	5.7441	6.0500	-0.3059	0.2163	0.0433	17	9.6800	2.5951	2.8300	-0.2349	0.1661	0.0332
18	120.0000	6.0231	6.2467	-0.2236	0.1581	0.0316	18	11.3500	2.2810	1.9300	0.3510	0.2482	0.0496
19	121.0000	6.0696	6.2100	-0.1404	0.0993	0.0199	19	8.2000	2.3633	2.8100	-0.4467	0.3159	0.0632
20	118.0000	5.9301	5.9633	-0.0332	0.0235	0.0047	20	14.0000	3.2716	3.5400	-0.2684	0.1898	0.0380
21	131.0000	6.5346	6.4467	0.0879	0.0622	0.0124	21	15.0000	3.4282	3.8567	-0.4285	0.3030	0.0606
22	139.0000	6.9066	6.5667	0.3399	0.2404	0.0481	22	15.0000	3.4282	3.7867	-0.3585	0.2535	0.0507
23	55.0000	3.0006	2.6267	0.3739	0.2644	0.0529	23	9.2000	2.5199	2.7100	-0.1901	0.1344	0.0269
24	50.0000	2.7681	2.7300	0.0381	0.0269	0.0054	24	5.6000	1.9562	2.5300	-0.5738	0.4058	0.0812
25	60.0000	3.2331	2.8267	0.4064	0.2874	0.0575	25	11.0000	2.8018	3.063333	-0.2615	0.1849	0.0370
26	70.0000	3.6981	3.7400	-0.0419	0.0296	0.0059	26	11.8700	2.9380	2.313333	0.6247	0.4417	0.0883
	Worst case			0.7278	Average	0.0654		Worst case			0.8514	Average	0.0486

4. Conclusion

The paper shows the semi-automated inspection process for the car assembly companies.The tool can be a part of Industry 4.0 integration of the automobile company. The complexity of assembly operations of doors, tailgate, hood, and lights is still stopping the usage of the robotic systems and foremost the low labor cost in the production plays key role in full automation of processes. Therefore, the system described in the paper mainly focuses on the semi-automated process with involvement of the operator in line. The main objective was partial integration of zero-defect manufacturing for automotive company as a part of Industry 4.0 implementation.

The device utilizes the line laser of red light with wavelength of 605 mm and a smart phone as a camera and storing database. The images are processed on the Matlab program in order to extract the data for G&F measurement. The algorithm extracts the red light pixels and converts the image into binary form. Then the profile is extracted the G&F is taken on pixel basis after which the conversion from pixel world to real is done.

Statistical method shows that the average error is still high. The reason for that could be the feature of the red light and the color of the vehicle that was in use. The prototype camera is the Samsung Galaxy 10s camera that is used for taking measurements.

The camera itself does not show quantum efficiency in that particular wavelength. However, the usage with the other type of smartphones is still possible. The special camera system for industrial application should be used in order to develop a reliable data system.

The other drawback of the system lies in the fact that it is almost impossible to use it outdoors, as the experiments and the system was developed in laboratory. However, the inspection process for the G&F inside production is also indoors, that is why we can conclude that there is no need to use it outdoors.

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