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Three dimensional pattern detection of multiple moving objects based on IR sensor solution

***Abstract**. Publication describes different approach to automatic pattern detection problem by implementing IR technology and combination of two algorithms, respectively responsible for high precision depth value measurements and corner detection. Application utilizes Intel R200 device to observe whole side of the pallet with one single verification pass. Only one frame is taken at one moment to check all the boxes at once. Solution takes advantage of algorithm derived from extensive experiments and connects it together with corner detection method to achieve efficient pattern recognition process. Crucial part of this project consists of method built to compile results and store depth values of corners for stack of boxes. Goal is to use computers processing power to lower amount of sensors used in this process and cover the gaps in visibility with smart algorithm that utilizes matrix of depth data generated by IR device.*

***Streszczenie.** W publikacji opisano odmienne podejście do problemu automatycznego wykrywania wzorów poprzez zastosowanie technologii IR oraz połączenia dwóch algorytmów, odpowiadających odpowiednio za bardzo precyzyjne pomiary wartości głębokości oraz wykrywanie narożników. Aplikacja wykorzystuje urządzenie Intel R200 do obserwacji całej strony palety za pomocą jednego przejścia weryfikacyjnego. W danym momencie wykonywana jest tylko jedna klatka, aby zaznaczyć wszystkie pola na raz. Rozwiązanie wykorzystuje algorytm wywodzący się z szeroko zakrojonych eksperymentów i łączy go z metodą wykrywania narożników, aby uzyskać efektywny proces rozpoznawania wzorów. Istotną częścią tego projektu jest metoda zbudowana w celu kompilowania wyników i przechowywania wartości głębokości narożników stosu pudeł. Celem jest wykorzystanie mocy obliczeniowej komputerów w celu zmniejszenia liczby czujników wykorzystywanych w tym procesie i zakrycie luk w widoczności za pomocą inteligentnego algorytmu wykorzystującego matrycę danych o głębokości generowanych przez urządzenie IR. (**Trójwymiarowe wykrywanie wzorców wielu poruszających się obiektów w oparciu o rozwiązanie czujnika podczerwieni**)*

Keywords: Infrared sensors, Pattern detection, Corner detection, Shape check
Słowa kluczowe: Czujniki podczerwieni, Detekcja schematów, Detekcja narożników, Wykrywanie kształtu

Introduction

Automatic pattern detection is a well-known problem occurring in high volume production environment [1] [2]. Many quality control processes are utilizing the newest existing technologies to prove that there are no faulty goods supplied to the end-customer [3]. End of line section of production plant is where the final full-priced samples are packaged into boxes and sent to the recipients. Goods have to be properly sealed to avoid damages and stability issues in transportation [4]. Pattern check measurements [5] conducted with boxes stacked on the pallets are performed by multiple sensors, often based on sound or laser reflections. Complex devices are producing precise and repeatable results to assure that all sides of the pallet are completely flat. No box can stick out of the pallet because it could create major problems with loading on a truck, plane or ship. End of line section of production plant is therefore the place to make final verification of the pallet shape.

This paper goal is to prove that currently used pattern check solutions can be replaced with simpler method, even less prone to the reflection errors. Clear gap on the market was found, with no other solutions capable of conducting the task in similar way and with device as simple as Intel R200. For the needs of this paper, basic 3x3x3 pattern with 260mm sized rectangular shaped products is also proposed in chapter 3. It will be used across whole paper to explain basics of palletization process [6] and verify results of the simulation.

Data required to prove information stated in this paper was gathered at end of line systems in European production plants, mainly from Fast-Moving Consumer Goods (FMCG) sector. Observations were conducted on high capacity lines, where pallets of products were transferred with frequency of up to 150 stacks per hour. This paper will present method that can be easily implemented at End of Line (EOL) stage of even most basic production facilities and still achieve results that will be sufficient for pallet verification process.

Background

Modern palletization systems are using robotic systems to place the boxes in proper positions on the pallet [7] [8]. Robots require dedicated gripper that will allow quick movements and precise placing. It is built especially to avoid additional expensive camera detection systems to verify how previous boxes are already placed on the pallet. Most common design is the forklift gripper, with one non-moving plate that slides between the products on currently built layer (Fig.1).

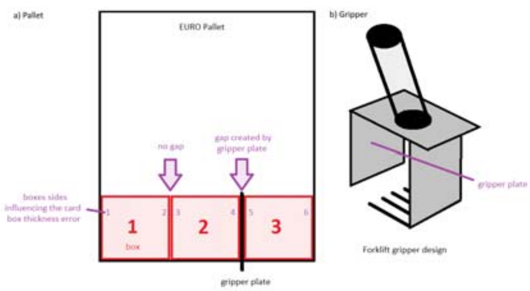

Fig.1. Pallet palletization pattern on EURO pallet and forklift gripper design

Forks are supporting the product from the bottom and are retracted when final position is reached. Design of the gripper used for palletization forces the gap between the boxes [9]. Depending on the packages weight and size, gripper plate thickness is ranging between 2 to 3mm. This value is required to achieve non-bending 300x300mm steel plate. Such plate is required to palletize pattern proposed in this paper with products size of 260mm, which translates into closely 1/3 of EURO pallet short side width (Fig.2). With such pattern there will be one gap left between the boxes in the robot program. Gap between boxes No. 1 and 2 will be eliminated by pushing box No.2 with box No.3 while placing it on the pallet. There will be no additional product to also push box No.3 further to the left side. This one gap between boxes No. 2 and 3 will be left on the pallet and has to be taken into consideration when calculating margin of error for palletization process.

Most common boxes used in logistics are utilizing B type of fluting according to norm PN-P-50000:1992 [10] with E, B or D profile. This translates into card box thickness in range 1.1 - 4.0 mm. ISO norm allows error of maximum 0,3 - 0.6mm in thickness to still meet the standard of selected profile for the boxes [11].

With this information it can be calculated that maximum margin of error for three 260mm wide boxes put in one row on one EURO pallet can reach up to 5.6mm.

Robot gripper creates 2mm gap [12], and six vertical boxes parts (Fig.1) can be produced with card box side 0.6mm slimmer than specified. This calculation presents worst case scenario but it shows clearly how ineffective is the usage of very precise sensors if boxes can be shifted by 2 to 5.6mm on every layer. Solution with lower precision can easily do the same job and still detect significant shifts in pallet pattern surfaces.

Proposed solution to the problem

Presented application verifies positions of boxes palletized on the pallet. It checks if all the packages are forming flat and even surfaces on all sides of the shipping stack. At first, Infra-Red (IR) sensor maps side of the pallet [13] and generates matrix of depth values consisting of 0.3 million points. This data is used by filtering algorithm to increase the precision of conducted measurement. It passes through 5 filters to achieve proven in previous studies 0.2mm precision [14].

In the next stage application searches through filtered data for indications of points with package corners. Finally, most suspicious values are used to deduct if all the boxes edges are within the range that can be tolerated in shape check process. It would also be possible to catch the pallet in movement, analyse depth values of the corners and deduct if boxes are placed properly without stopping the conveyors. This is possible because IR technology does not suffer from focus deterioration when beam is reflecting from objects moving at moderate speeds. Most of the currently used solutions would require stoppage of the pallet for around one second to conduct such measurement. Capabilities of R200 device (90FPS) allow to execute even multiple verification passes for each pallet [15].

Device is perfectly capable of distinguishing single boxes as shown on Fig.1. This experiment presents six examples of graphical representation for values stored in depth data matrix, previously downloaded from IR sensor. Application is clearly capable of distinguishing boxes on a pallet palletized with 3x3x3 pattern. In 3D view it is even possible to locate the label placed on sides of the boxes.

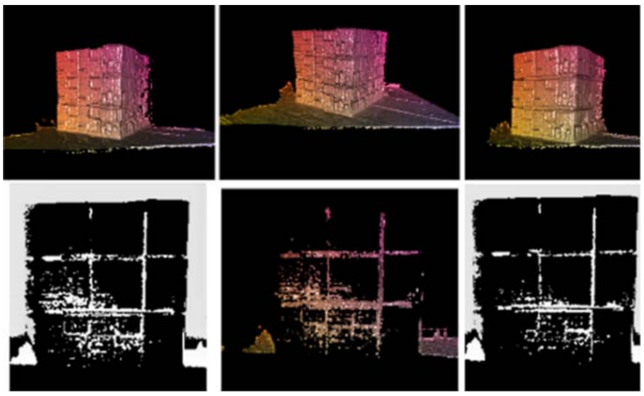

Fig.2. Depth recognition tested on 3x3x3 boxes pattern. In both voxel 3D and standard IR 2D views, gaps between the boxes are clearly visible and singular packages can be distinguished by the algorithm.

This part of application was completely built from scratch for experiments conducted in mentioned paper [14] and software created in C# language was written especially for the simulations. Model results from Fig.1 can be accessed in form of data matrix (pre and post filtered by algorithm).

IR precision enhancement algorithm

In this paper, basic version of scientifically proven filter-based precision algorithm is being used [14]. To implement this method for purpose of shape check verification, there was modification done to make up for loss of RGB data. Possibility of enhancing results with RGB camera stream was not an option, because fully automated production lines are already often working autonomously in dark environment of Industry 4.0 [16]. Base colour *R* calculation had to be removed from the algorithm (1). To achieve high precision with only basic filtering, stated below improvements were added to the calculation method.

(1) $$R = \frac{C}{65536}, \ C \epsilon R$$

In comparison, with original algorithm, this application produces almost twice as many samples. In such case it is recommended to soften the slope of function *f(x)*, which is used for aggressiveness of error detection [14]. Used in this application function $f(x) = D\hat{}(x-5)$ will avoid problems with suppressing negative effect of higher amount of samples (Fig. 3).This resulted in modified equation for each filter stage:

(2) $$X_n = sgn^2(X_n - X_c)\left|sgn\left(X_n - \left(\left(0{,}25 f_z(\tfrac{5n}{r})\right) sgn(X_n - X_c) + 1\right) X_c\right) X_c\right|$$

Amount of filters was kept at original value of *r=5*. Equation used for depth value of each pixel (last pass, through filter *n=5*) was specified (3). After introduction of standard deviation final algorithm for this specific task of pattern recognition was achieved:

(3) $$X = sgn^2(X_5 - X_c)\left|sgn\left(X_5 - \left(\left(\frac{s}{P_r} f_z(5)\right) sgn(X_5 - X_c) + 1\right) X_c\right) X_c\right| + X_c\left(1 - sgn^2\left(X_5 - \left(1 - \frac{s}{P_r} f_z(5)\right) X_c\right)\right) + X_c\left(1 - sgn^2\left(X_5 - \left(1 + \frac{s}{P_r} f_z(5)\right) X_c\right)\right) + X_c\left(1 - sgn^2(X_5)\right)$$

X, Xc ϵ R, where *Xc* is the currently measured point. *X* is the final value of the analysed pixel. Equation (3) is used as a base for further calculations. In further chapters, corner detection algorithm will use data generated by this method.

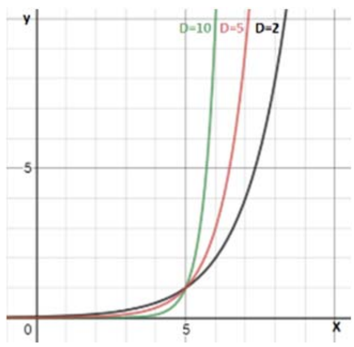

Fig.3. Function behaviour with values of *D=2, D=5* and *D=10*. Above value of 10 chart is stabilizing.

Twelve neighbour's algorithm

In conducted experiments it was found that the best results of corner detection can be achieved with analysis of 12 points, which are always required in strictly stated positions around the investigated point taken from IR data matrix (Fig.4). Those values are connected with requirements of Shi-Thomasi algorithm, which is explained in next chapter. Edge values of the depth data matrix had to be excluded from the calculation's area to properly distinguishing the corners. Two lines of pixels from each side of the matrix were omitted by the process. It was done because it was required to always use values of full 12 points of data from cross-shaped scheme shown in Fig.4. In total, 4472 pixels had to be excluded from the algorithm (~1%).

With filled data matrix available, next target was to find fair dependence between pixels closer and further from the point under verification, without risking loss of information containing coordinates of the edges. Challenge was to find such relation that would show rising or falling values in response to how far verified pixel is from the closest corner. Specific scheme of 12 neighbours was also designed especially to make sure that even only 1 pixel gap between the boxes can be distinguished properly.

Algorithm shows similarities with seeded region growing algorithm, which recognizes where the higher ground is ending or starting [17]. Similar idea is being used in presented solution.

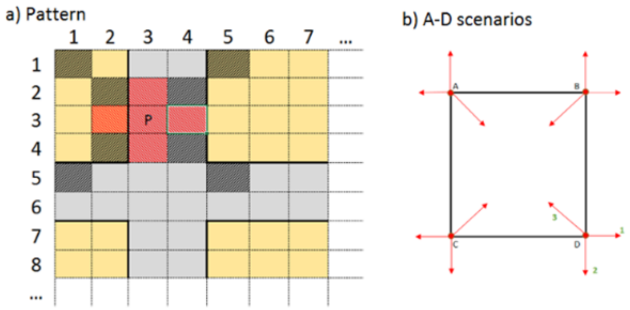

Fig. 4. Pattern of 12 points used by the algorithm and first possible position that can be verified (3, 3). Possible scenarios A-D and three vectors that are required to solve the corner detection problem

Presented scheme can be explained simply with use of different colours (Fig.4). Red colour indicates the closest neighbours, where it is expected to find two edges if point P turns out to be a corner. Black points are indicating farther neighbours, which will indicate start of flat box surface if again, point P turns out to be a corner. Red points are used as the baseline for corner detection. If sum of values of red pixels is lower than sum of black points, then whole eq. 5 will achieve positive value. As explained in next chapter, such situation will indicate that algorithm has found a corner.

Corner detection

Search for the corners requires usage of dedicated algorithm that will be able to properly utilize available data. Currently the best results for corner detection of 3D object projected onto the 2D plane can be achieved with Shi-Thomasi method [18] [19]. It is also perfect for implementation in this solution as it states that only the eigenvalues should be used to check if the pixel is a corner [17]. It assumes that there are minimums in both X and Y axis that clearly point to a corner. This is stated in equation: $R = \min(\lambda_1, \lambda_2)$.

In S-T algorithm threshold value ($R_{threshold}$) indicates status of corner verification process. It has to be compared with value R, which is calculated for every pixel in the matrix. Those values are used to verify if eigenvalues $\lambda 1$ and $\lambda 2$ reached the minimums [20]. Corner is found if both minimums are achieved. To check if the current pixel is in the middle of the corner, comparison of depth values of three vectors is required. One horizontal and one vertical are used to check if the deeper areas (gap between boxes) are in the vicinity of current pixel. Third one (at angle of 135 degrees) confirms if the box flat surface starts expanding from the point of the corner or is it just a random error (Fig.3). It is also mandatory to check all four corner variants (top left = A, top right = B, bottom left = C, bottom right = D) to verify position for the box (4). Three values are required for each corner, for all of them all 12 neighbours stated in previous chapter are being used.

$$X = \frac{X_{AX\pm1,AY\pm1} + X_{AX\pm2,AY\pm2}}{X_{AX\pm1} + X_{AY\pm1}} \quad (4)$$

S-T minimums can be presented with two colours, grey for deep areas, such as gap between the boxes, and yellow for flat surfaces of the product (Fig. 4). Algorithm searches for the first encountered grey pixel by checking all the points on both axis at the same time, constantly trying to reach point (0, 0). Depth value matrix resolution is roughly equal to VGA = 640x480px [21]. By referencing specific pixels in depth value database, corner detection algorithm can be presented in form of one equation, used for all possible scenarios (5).

$$X = \frac{2(X_{c-1}+X_{c+1}+X_{c-640}+X_{c+640})}{X_{c-641}+X_{c-1282}+X_{c-639}+X_{c-1278}+X_{c+641}+X_{c+1282}+X_{c+639}+X_{c+1278}} \quad (5)$$

To check if currently verified point X is the corner, all 12 neighbours values should be put into eq. 3. Range of values reached by equation makes it possible to easily distinguish parts of the gap between the boxes, vicinity of the corner, box orientation and finally also the corner point itself. To present it graphically, it was assumed that high values of the box surface are equal to 1 and lower (deep) values of the gap are equal to 0 (Fig. 5).

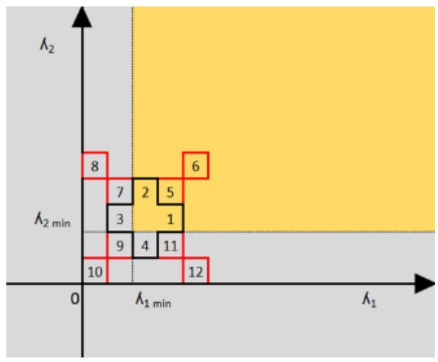

Fig. 5. λ minimums and points used by the corner detection algorithm (1-4 for top part and 5-12 for bottom part of the eq. 3).

Last step of S-T corner detection algorithm is calculation of $R_{threshold}$, which will be used to determine if the value X reached by pixel is high enough to qualify it as the corner.

By using the same depth values matrix as before it is possible to calculate average value of depth from middle points of all the boxes available on the pallet (Fig.6). Amount of boxes and their sizes will be needed to calculate the middle points. This information can usually be scanned from the bar code of any product on the pallet [22].

If stated relation between higher and lower points will be kept (higher value = higher point) it will be possible to summarize the search for corner with simple check (6).

(6) $$if\ (X = R > R_{threshold})\ then\ X\ is\ a\ corner$$

In this case, assumption was made that all the sides of the boxes are even and flat. In real application there will be threshold for this condition as boxes are never fully flat. Pieces might even damage the box from the inside [23].

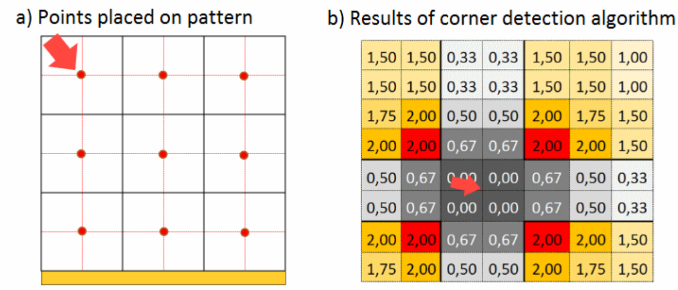

Fig. 6. Points to be taken as average value for calculation of $R_{threshold.}$ Result of corner detection algorithm calculated with eq. 3.

Flatness check

With method that can detect corners within depth data database it is possible to finally calculate how flat the pallet actually is. At this stage, it is finally possible to check if there is any work left for the operator on the line. Example of 56 points fragment from the database, place just between four boxes on the stack was calculated and presented in Fig.6. Algorithm found four corners (red colour) and properly distinguished neighbours, dividing them into gap (grey) and surface of the box (yellow) categories.

With properly found corners it is possible to compare depth values only for those specific points to indicate if any of the boxes are sticking out of the pallet. It is also possible to state if box is at an angle with only fragment of the package outside the stack or is it whole piece palletized by robot in wrong position. For one side of the pallet with 3x3x3 pattern algorithm will estimate boxes position by comparing 36-108 points, which should take milliseconds for any currently available PC.

All the values verified as the corners should be left in the matrix, others can be zeroed. This will allow to operate only on data that is important in this application. Range of depth values accepted for OK pallet, should be determined beforehand, right after the application installation. If industry non-official standard is to be kept, then the threshold should be lower or equal 5mm. To minimize the amount of errors it can also be verified how many points are outside the range. There are, at least, three points that can be tested for each corner (values of 2.00 from Fig.6), depth error should be triggered only when two or more of them are outside allowed depth range. It will increase amount of points to be verified from 36 to 108 for each pallet pass with 3x3x3 pattern. Operator should be able to see on the HMI screen which corner didn't meet the quality criteria.

Conclusion

This solution describes practical application of IR sensor in production industry. It presents how to modify IR precision improvement algorithm, connect it with S-T corner detection and how to manipulate depth values matrix to properly provide data for both calculations. Conducted test for detection of 9 boxes at the side of 3x3x3 pallet confirmed that each corner was detected with precision lower than expected 5mm. Average margin of error observed during the tests was close to 3mm, which is similar to threshold of most precise systems available on the market (for example Mechmind [24] solutions). Tests conducted for the needs of this publication confirmed that as long as maximum FOV of camera lens is not surpassed and resolution still allows to distinguish 12 pixels for each corner, it is possible to conduct verification of flatness for side of the pallet with precision =< 5mm.

There is possibility to build simple pattern check solution for pallets filled with products. It can be implemented with software that will indicate to the operator if the corners of boxes are OK/NOK. This solution should interest process engineers working on high capacity production lines as it can be used as additional quality check to further increase the percentage of good products assembled inside the plant.

REFERENCES

[1] H. Zeller, G. Doemens, "Applications of pattern recognition in semiconductor and printed board production", *Signal Processing*, Volume 5, Issue 5, pp. 399-412, 1983. [doi: 10.1016/0165-1684(83)90003-8]

[2] K. Horak, M. Richter I. Kalova, "Automated flaws detection on bottles in food industry", *Annals of DAAAM & Proceedings*, DAAAM Int., Vienna, 2009.

[3] B. Mehenni, M.A. Wahab, "APRIS: Automatic Pattern Recognition and Inspection System", *1993 CompEuro Proceedings Computers in Design, Manufacturing and Production*, pp. 23-28, Pris-Evry, 1993. [doi: 10.1109/CMPEUR.1993.289825]

[4] H.J. Steudel, "Generating pallet loading patterns with considerations of item stacking on end and side surfaces", *Journal of Manufacturing Systems*, Volume 3, Issue 2, pp. 135-143, 1984. [doi: 10.1016/0278-6125(84)90004-9]

[5] M. Schuster, R. Bormann, D. Steidl, S. Reynolds-Haertle, M. Stilman, "Stable stacking for the distributor's pallet packing problem", *2010 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 3646-3651, Taipei, 2010. [doi: 10.1109/IROS.2010.5650217]

[6] Sakamoto, T.; Harada, K.; Wan,W. "Real-time Planning Robotic Palletizing Tasks using Reusable Roadmaps". *J. Robot. Netw. Artif.vLife 2020*, 6, 240.

[7] Padhy, Shyam. (2017). Palletizing Application of a Six-axis Industrial Robot. 10.13140/RG.2.2.12745.19043.

[8] Hashimi, Hira, G. Yedukondalu. 2020. "Automatic robotic palletizing for oil cartons," *Int. J. Mech. Prod. Eng. Res. Dev.* 10 (4): 1-10.

[9] Wojciech Kaczmarek, Szymon Borys, Jarosław Panasiuk, Michał Siwek, Piotr Prusaczyk, 2022, "Experimental study of the vibrations of a roller shutter gripper.", *Applied Sciences (Switzerland)*, 12(19) doi:10.3390/app12199996.

[10] *ISO Norm: PN-P-50000:1992*

[11] M. Bielecki, A. Chmielewska-Wurch, T. Damięcki, B. Patalan, M. Słoma, S. Żdziebło, "General issues and the recommended standards for corrugated board and corrugated board packaging", *The Association of Polish Papers*, 2011

[12] Jarosław Panasiuk, Wojciech Kaczmarek, Michał Siwek, Szymon Borys, 2022, "Test Bench Concept for Testing of Gripper Properties in a Robotic Palletizing Process*", Problems of Mechatronics. Armament, Aviation, Safety Engineering 2022*; 13 (2): 51-64; ISSN: 2081-5891 | E-ISSN: 2720-5266, DOI: 10.5604/01.3001.0015.9065.

[13] A. Rogalski, K. Chrzanowski, "Infrared Devices and Techniques (Revision)", *Metrol. Meas. Syst.*, Vol. XXI, No. 4, pp. 565-618, December 2014.

[14] P. Szablata, P. Łąkowski, J. Pochmara, "Processing depth distance data to increase precision of multiple infrared sensors in the automatic visual inspection system", *Optical Engineering 56(8),* 083106, SPIE, 24 August 2017. [doi: 10.1117/1.OE.56.8.083106]

[15] Intel® RealSense™ Camera R200 Embedded Infrared Assisted Stereovision 3D Imaging System with Color Camera, *Product Datasheet*, Intel, June 2016.

[16] D. Gorecky, M. Schmitt, M. Loskyll, D. Zühlke, "Human-machine-interaction in the industry 4.0 era", *2014 12th IEEE International Conference on Industrial Informatics (INDIN)*, pp.

289-294, Porto Alegre, 2014. [doi: 10.1109/INDIN.2014.6945523]
[17] A. Mehnert, P. Jackway, "An improved seeded region growing algorithm", *Pattern Recognition Letters 18*, pp. 1065-1071, Elsevier, 1997.
[18] A. Ajay, D. Venkataraman, "A survey on sensing methods and feature extraction algorithms for SLAM problem", *Cornell University Library*, 2013. [arXiv: 1303.3605]
[19] J.L. Muñoz, D. Pastor, P. Gil, S. Puente, M. Cazorla, "A study of 2D features for 3D visual SLAM", *The 43rd Intl. Symp. on Robotics (ISR2012)*, pp. 29-31, Taipei, Taiwan, Aug. 2012.
[20] J. Shi, C. Tomasi, "Good Features to Track", *Proc IEEE Conf. on Computer Vision on Pattern Recognition (CVPR)*, pp. 593-600, Seattle, 1994.
[21] J. Smisek, "3D Camera Calibration", *MSc. Thesis, Czech Technical Univesity, Prague (Czech)*, 2011.
[22] T. Sriram, K. Vishwanatha Rao, S. Biswas, B. Ahmed, "Applications of barcode technology in automated storage and retrieval systems", *Proceedings of the 1996 IEEE IECON. 22nd International Conference on Industrial Electronics, Control, and Instrumentation*, pp. 641-646, vol. 1, Taipei, 1996. [doi: 10.1109/IECON.1996.571035]
[23] J.P. Hermann, "Pattern Recognition in the Factory: An Example", *Robot Vision. International Trends in Manufacturing Technology*, Berlin, Springer, 1983. [doi: 10.1007/978-3-662-09771-7_20]
[24] Mech-Eye Industrial 3D Camera, *Technical Specification V3*, Mech-Mind, 2023.