Intelligent Digital Tutor to Assemble Puzzles Based on Artificial Intelligence Techniques

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Abstract. The potential of applying image processing tools and artificial intelligence in learning processes is identified. This article presents the development of a digital tutor that helps solve a puzzle. Point cloud technology is used to identify each person's interaction dynamically in space. The proposed methodology is developed in several stages. The first stage consists of the acquisition and pre-processing system for adquaring the user environment. The second stage consists of recognizing the piece in the puzzle, at this stage it is necessary to develop a database of the particular puzzle. In the identification process, the PCA algorithm is implemented as a complementary strategy to the use of the neural network. The last stage implements a general search algorithm as the core of the decision system. This methodology is presented as an iterative process and evolves over time according to the interaction with the user. The results are presented through confusion matrix which exhibits a performance of 92.7% assertiveness. Finally, the potential of using this methodological structure in different cognitive processes with puzzles with different levels of difficulty is raised.

Keywords: 3D Image-Processing · Intelligent-tutor · Search-algorithms · ANN · PCA

1 Introduction

Currently, the development of technologies in the world has increased, requiring people who are competent in areas such as science, technology, engineering and mathematics, known as STEM outcomes (Science, Technology, Engineering and Mathematics). According to the Office of the Chief Economist of the United States, STEM occupations have increased over the past 10 years by almost 24.4% while other occupations have increased by 4% [21]. In this context, the automation of the human learning process is presented as a tool for developing STEM skills.

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Research in human learning area is widely discussed in the literature, in Bloom [1] authors have shown that a person with a personalized tutor significantly improves the performance of learning process, results show improvement above 90% in contrast to conventional learning processes in groups. Personalized tutoring with robotic systems has begun to receive attention of scientists, but it is still relatively little explored [2]. Despite investments of tens of billions of dollars, the problem of development education at global scale remains unsolved [3]. An interesting approach in which Robots focuses on learning and interacting with children is proposed by a study that covers the effects of two different social roles of a robot "peer vs. tutor" on children's tasks [4]. Other social skills, such as teamwork, are investigated using cutting-edge technologies such as virtual reality [5].

Image processing has positioned itself as a powerful field in the process of interaction with the environment, applied research shows this [6–8]. In this research, image processing is an important component since it allows interaction with the decision-making system based on artificial intelligence techniques.

The potential of point cloud technology is identified because it presents the possibility of interacting in three-dimensional space. This field of research has been developing through cumulative effort provided by a free software community [11]. Other studies evaluate the effects of using the Kinect camera as a depth and color sensor, effects related to precision and resolution in the mapping of three-dimensional spaces [12]. While other works present the detection of human activity [13]. These works demonstrate the potential of using this technology as a base tool to detect the interaction of a person in space, in this research, related to the pieces of a puzzle.

Assisted learning has been the subject of research in various fields of knowledge. The computer-assisted dental patient simulator, DentSim is a significant advance that has enabled dental students to acquire cognitive-motor skills in a multimedia environment [14]. It is a high-tech unit developed from the classic dental simulator. Not only can this system standardize and improve the students' dexterity, but also does the training module make preparations easier to be visualized and provide immediate feedback, real-time user-generated evaluation by using advanced imaging and simulation technologies via the built-in 3D scanning system [15]. The feedback that the researchers propose has two interesting characteristics. The first is based on real-time focus and the second is based on image processing, the latter consists of generating the 3D image from the spatial information provided by the instrument head. In this context, the research presented in this document could be useful since it would allow sensory fusion with the system already implemented. In this sense, the main contribution of this research is how image processing as a tool to capture reality is integrated with artificial intelligence tools to interact with the user and lead to a digital-intelligent tutor. Another similar investigation reports the use of a digital tutor to accelerate knowledge acquisition and improve their preparation for the civilian workforce, this tutor to develop veterans' technical expertise and employability [16].

At a technological level, this tutor is based on a computer-assisted learning system and the only interaction with the user is through the keyboard and mouse of a computer. This approach has been presented in several investigations in different fields of application [17,18]. It would be of great research value if this type of computer-assisted system integrates interaction with the user as developed in the methodological proposal of this research. The main contribution of the methodological proposal presented in this document is based on the possibility of monitoring all the interactions of students through image processing. It is presented as a useful tool in the search to develop structures to capture the social skills of students that allow the instructional management of warmth, commitment and determination. It would be a complement to computer-assisted systems that visualize education as children interacting with online learning systems where based on past performance and algorithms offer what each student needs to know [19]. The biggest recent advance in smart tutors is presented by IBM and Pearson [20]. They have partnered to develop intelligent dialogue-based tutoring systems. This development is based on advances in machine learning and natural language processing to create a Watson dialog-based tutor (WDBT). In this sense, the main contribution of this research is presented as a methodological development that would allow the integration of image processing as useful information to the systems currently developed. Although the field of artificial intelligence is growing rapidly and specifically the area of computer vision and it is of investigative value to present how these advances are integrated into different fields of action. In this case, the learning systems that could be as varied as people and areas of knowledge exist.

In this article a puzzle is presented as a case study, the methodological structure of the research proposal is developed. This is structured in three stages, the first stage covers the acquisition and pre-processing system based on the acquisition of a point cloud. The second stage consists of generating a part identification system based on artificial intelligence techniques to finally generate a decision-making system by executing a general search algorithm. This process is presented iteratively using a graphical interface. The structure of this document is developed as follows: in section two the methods are put forth, in section three the experimental configuration of the methodological proposal is presented, in section five the experimental results are shown and finally in section six the discussion of the results and conclusions.

2 Methods

Our intelligent tutor is aimed at children from 3 years of age onwards, as it is a very important stage for asserting skills related to learning and cognitive development. To start the tutor, it is required to have access to a computer with the programme settings, follow the tutor's instructions, and finally it is recommended that an adult be responsible for the child.

This kind of system could be useful by stakeholders as: teachers, peers, schools and educational institutions and those who wish to incorporate the intelligent tutors in their learning programs.

This tutor is developed in several phases, integrating image processing techniques, machine learning and Search algorithms (see Fig. 1).

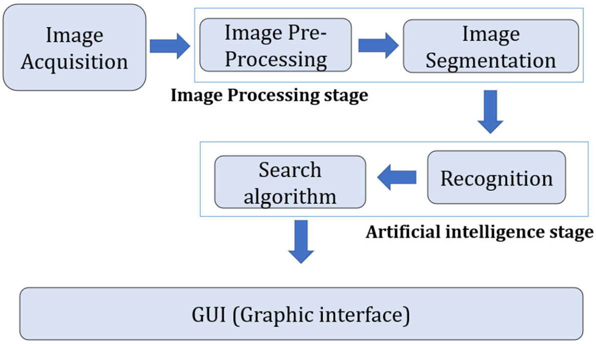

Fig. 1. General outline of the methodology

2.1 Acquisition System and Image Processing

Puzzle Selection. The pieces of the puzzle contain geometric figures of pictorial type and strong primary colors, in order to call children attention when solving this puzzle, as well a minimum amount of 12 pieces, for a level of complexity appropriate for children, the dimensions of the puzzle are 40 × 30 cm. The size of each piece is 10 × 10 cm for easy manipulation (see Fig. 2).

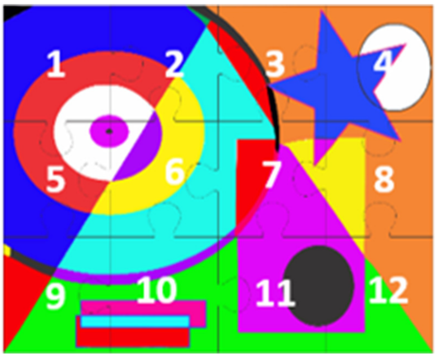

Fig. 2. Puzzle with labels

Image Acquisition and Pre-processing. The Kinect 2 v2 camera was chosen for its outstanding features, including image resolution, a field of view, computer connection, and compatibility with the operating system. Before capturing the environment, the color sensor and depth sensor are configured to get an RGBD (RGB color depth and space point cloud). The result of this capture is a point cloud called PCraw, which is a set of points in 3D space (PCraw: [x, y, z]), the point cloud has a color resolution of 1920 * 1080 px. Therefore, the reference system of a PCraw point represent its position concerning the sensor at which it was acquired (see Fig. 3). The ROI (Region of Interest) function is implemented to constrain the object in space, for this, ranges are defined in the space associated with the x, y, and z coordinates.

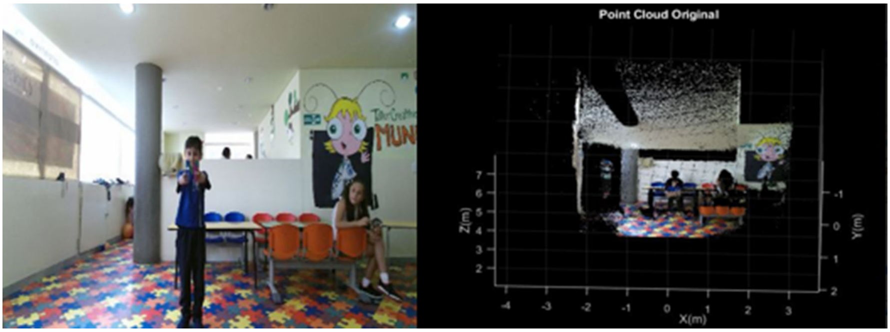

Fig. 3. Color Image and PCraw

Image Segmentation. The image obtained has traces of skin, so a color segmentation is made, taking as a reference the study [9] to HSV of skin images with different tones and their respective histograms to identify the range of values for skin, from this experiment we obtain that the threshold is at $0 < H < 0.18$, $0.5 < S < 0.9$ and $0.2 < V < 0.95$.

2.2 Machine Learning

Principal Components Analysis - PCA. Descriptors contain the raw information for each image, by itself, they have great dimensionality, so makes difficult, the training of the classifier, because it consumes great amount of computational resources, learning time, and/or execution of the program; therefore, a dimensionality reduction of the number of variables (features) of the images must be done.

To carry out dimensionality reduction of the images, PCA was applied, the following steps were taken into account: 1) Average (center the data). 2) Variance, Covariance (How the data set looks). 3) Eigenvectors and eigenvalues of the covariance matrix. 4) Project the data in the dimension where the greatest dispersion of information is observed.

ANN. For the recognition of the puzzle piece in the digital tutor, an artificial neural network is developed, which are networks that simulate the biology of the human brain and its neurons, these are connected to each other, through small programs that are responsible for processing the data and identify the patterns that are indicated with labels.

The neural network takes the descriptors received from the PCA process as inputs, which contains the main information from the puzzle image database and returns the labels that correspond to the selected pieces.

2.3 Search Algorithm

This tool (tutor) generates the next piece for assembling the puzzle based on an uninformed search algorithm, which has no additional information on the problem, generating successors to next states and distinguishing one state that is a solution and another that is not [10], (see Fig. 4).

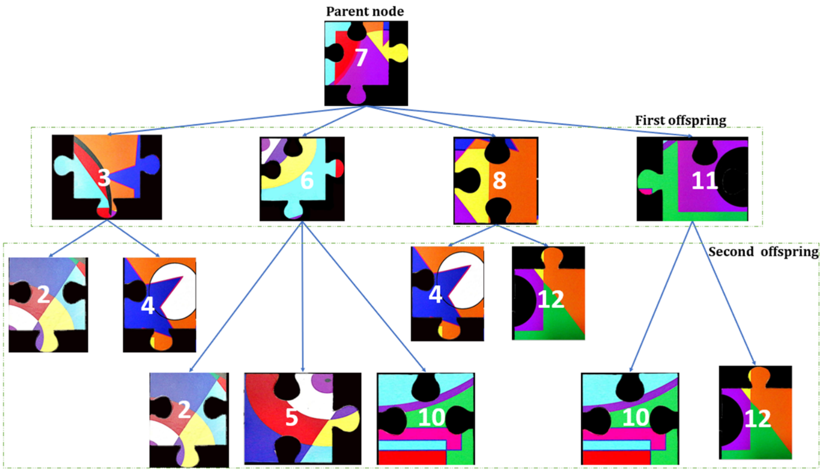

Fig. 4. Uninformed search algortihm scheme

3 Experimental Setup

3.1 Image Acquisition and Pre-processing

In this phase, the point cloud, available further than 0,5 m from camera sensor, corresponding to a piece of puzzle, must be placed in a larger space to obtain a good definition in color and depth. Then it is filtered in space using the pcfitplane function which is a variant of the RANSAC algorithm (Random Sample Consensus), where the maximum distances of the point cloud are adjusted, and returns a geometric model that describes the plane, additionally returns the indices that are in and out of the plane. These position ranges are entered into a function of the program, which is based on the ROI (region of interest) processing technique, which takes a portion of the image where is the piece held by the user. The information about the location of the puzzle piece in the scene is obtained, the indices of this process return the image in 2D, and then proceeds to crop and eliminate the noise in the (imcropped) image, (see Fig. 5).

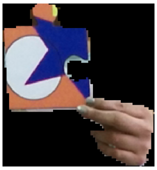

Fig. 5. Image with ROI

Image acquisition and pre-processing is related in the algorithm below. Where a spatial filtering is done with the ROI function with restrictive conditions in the X, Y and Z coordinates, to later obtain an RGB image, which contains the puzzle piece and part of the hand, and the segmentation process can continue by color.

Algorithm 1. Image Acquisition and pre-processing, the input is the PCraw and Original Image and return a filtered image in space

$pcfitplanef$ ← extract planes of point cloud and returns the surfaces, the model, and other parameters
$pc - roi = select(pc - raw, index)$ ← select sub point cloud
$matrixofImage$ ← create matrix m*n
for i=1:n **do**
  $ind - pix$ ←values of each color index color is reconstructed
  $Image2D$ ← create image 2D
  $imcropped$ ← crop image of piece
end for

3.2 Image Segmentation

In this phase, the ranges of the skin are selected at different color spaces such as: YCrCb, Lab and HSV, where the best segmentation to the skin was made in HSV color space, the ranges gave the following ranges of each channel were: 0 <H< 0.07, $0.1 < S < 0.52$, $0.3 < V < 0.85$. (see Fig. 6(a)), the result of this final segmentation is shown in (see Fig. 6(b)).

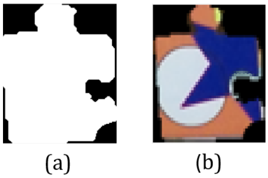

Fig. 6. Mask and Segmented image of puzzle piece

3.3 Principal Components Analysis PCA

The database[1] contains the images of each piece, the size of them is 50 * 50 * 3, the information is organized in a data structure as follows: 1) Data of the images 12000 * 7500. 2) Data of the labels that correspond to each image (Part Number), for a supervised learning 1 * 12000. The selected PCA number is (30) since it allows learning the neural network in less time.

3.4 ANN

In this tutor, an artificial neural network called newff was used, which is a feed-forward backpropagation network. This function requires the input arguments such as: Image information referring to the descriptors resulting from PCA; topology of the net; functions to activate layers and at the expected labels associated to each input descriptor. The neural network needs to learn patterns corresponding to each piece of the puzzle.

Algorithm 2. Neural Network the input of ANN is the descriptor of Image and return the label of pieces **L**

Database ← Database for test
Database ← Database for train
net ← newff with the arguments such as: Size Image, number of neurons, activation functions, layers
Train ← train with network training with the target value and the value obtained
sim ← simularion with model NN and test image (sample)
Create descriptor of Image new for test
Label **L**
Do the PCA of Descriptor Image
Label ← Predict piece with NN trained, return the number of piece selected.

[1] The entire puzzle database is available at: https://www.dropbox.com/sh/yirqf4xv7lrs13j/AACMKJb0QaklhsItmjXKD88oa?dl=0.

Input and Output Data. The database was divided into test information (30%) and training information (70%), in order to use one part for neural network training (entered in newff) and the other to check the network learning. The inputs of the neural network correspond to the value resulting from the dimensional reduction with PCA, it's (30) variables, and the outputs of the network correspond to the target vector, it's (12) labels.

Neural Network Architecture. The architecture of a neural network depends on four main parameters: (1) the number of layers in the system; (2) the number of neurons per layer; (3) the degree of connectivity and (4) the type of neural connections. A problem with this level of complexity can be solved with three (3) layers such as the input layer, output layer and hidden layer.

3.5 Uninformed Search Algorithm

There are several Uninformed search strategies, the used is in this tutor is the Breadth-first Search, this type can be implemented for actions that have the same cost and for problems that do not have highly complex searches, such as maze problems, maze problems, missionaries and cannibals problem and others.

This search takes as an strategy, that the first parent node, (root node, in this document, will be called father), is expanded (FIFO ordering principle), a successor list is created by its physical connection with its father in the sense of the assembly order, and subsequently its successor nodes (descendants).

The algorithm works as follows: 1) Start with the initial node that corresponds to the first selected piece of the puzzle. 2) A graph is created, which represents the assembled puzzle. 3). The list of successors corresponds to the links in the graph. 4) The successors (possible solutions) are rearranged randomly, to generate solutions to the next state in the assembly, without the successors repeating.

4 Experimental Results

The initial result of this investigation is a database associated with the case study, this has different perspectives related to rotation and translation, the effects of light variations are introduced and contains images with Gaussian noise and salt and pepper in ranges of 0.01 to 0.1. A total of 12000 images with twelve different pieces. RGB images are 50 * 50 in size for each channel. The first stage is to train the neural network, for this, the input layer of the network is configured. The number of neurons in the input layer of the network must be the size of the descriptor. Initially, the descriptor is the image organized by rows, this configuration has a size of 7500. The PCA algorithm is used to reduce this number of neurons with the aim to improve system performance at the processing time level. The result is a descriptor of 30 elements, therefore a reduction of

Algorithm 3. Seach algorithm the input of the algorithm is the label selected *L*

```
Create Node; temp var
Create Vector Open VO
Create Vector Close VC
N=length (Puzzle)
while Infinity loop to repeat do
  if void-vector(VO) then
    Return false
  end if
  Node←FirtElement(VO), extract the first label
  VC←add(VC,Node)
  if length(VC)==N then
    Return true
  end if
  function show.next.piece(Node)
  function offspring=sucessor(Node)
  for i=1:length(offspring) do
    if offspring(i)∉ VC then
      VO=add(VO,offspring(i))
    end if
  end for
end while
```

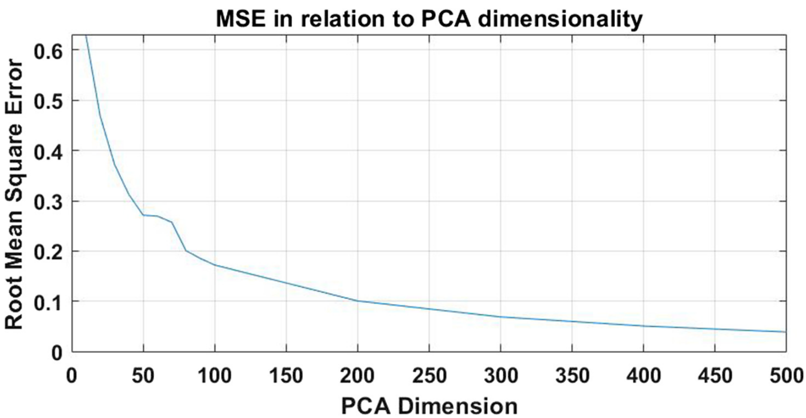

Fig. 7. Root mean square error in relation to PCA dimensionality.

250%. A graph (see Fig. 7) relates the effects of varying the dimension of the descriptor using the PCA algorithm is presented. The results show that with a lower degree of dimensionality, arround 30 PCA, the error does not increase proportionally as PCA components are added.

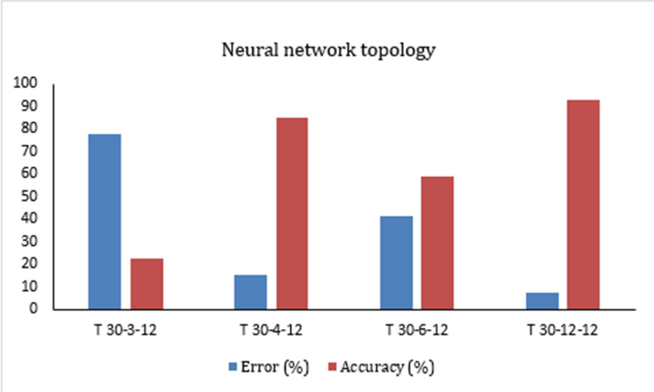

Fig. 8. Performance of four neural network topologies

A neural network with three layers has been defined as a universal classifier. The number of neurons in the input layer is the dimension defined in the PCA algorithm and the number of neurons in the output layer is the number of pieces of the puzzle, in this case, twelve. This approach limits the possible tests to the number of neurons in the intermediate layer, results of using 3 - 4 - 6 - 12 neurons respectively (see Fig. 8) allow it to define that the network topology that generated greater precision in the predictions is the 30-12-12 network (30 input neurons, 12 neurons in the intermediate layer and 12 neurons in the output layer).

The confusion matrix (see Fig. 9) is developed to assess the performance of the model. The configuration of the neural network confusion matrix is defined as 12×12, since the puzzle has 12 pieces. From this analysis, a learning accuracy of 92.7% and an error of 7.3% are obtained. The results presented in the confusion matrix allow it to determine the correct functioning of the neural network fed by the image reduced dimensionally with the PCA algorithm. After identifying the image in space it is possible to generate a decision engine. For this, a general search algorithm has been presented. In this case, the level of complexity is low and an "uninformed search algorithm" is defined. Results are presented using a graphical interface (see Fig. 10) On the left side, the graphical interface contains the user interaction functionality. On the right side, the identified pieces are presented and pieces are suggested for the armed. Search algorithm dynamically evolves with user interactions. To evaluate the performance of the integrated system, an evaluation of duration times of each stage of the process is developed. The system startup takes approximately 5 min, this process includes the execution of MatLab software and the compilation of the GUI graphical interface, communication verification (SDK) is also executed, with the Kinect sensor-camera (Fig. 10).

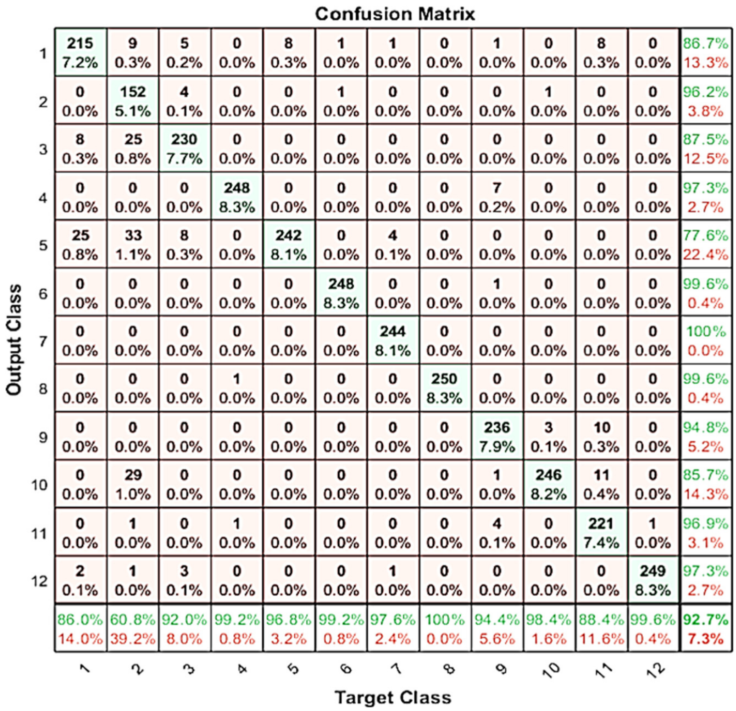

Fig. 9. Confusion matrix

A reference parameter analyzed is the assembling of puzzles in a natural way, for this, a young person takes an average of 2 min in the assembly process, a child takes ten times more depending on age. With the proposed system, five moments are identified, the first moment takes 45 s and consists of "Capturing" the image, the second moment takes less than 20 s and consists of segmenting the captured image, the third stage takes less than 10 s and consists of identifying the puzzle piece by trained neural network, finally, the last stage takes less than 5 s and it consists of generating the suggestion of assembly by means of the search algorithm. The total system takes an average of 25 min to assemble the puzzle because it requires user interaction. A total of 25 tests were performed with different people in a range of 3 to 11 years. It should be noted that the experimentation tests were carried out on a computer with a Windows 10 operating system, 8 GB RAM and an Intel (R) Core (TM) i5 processor.

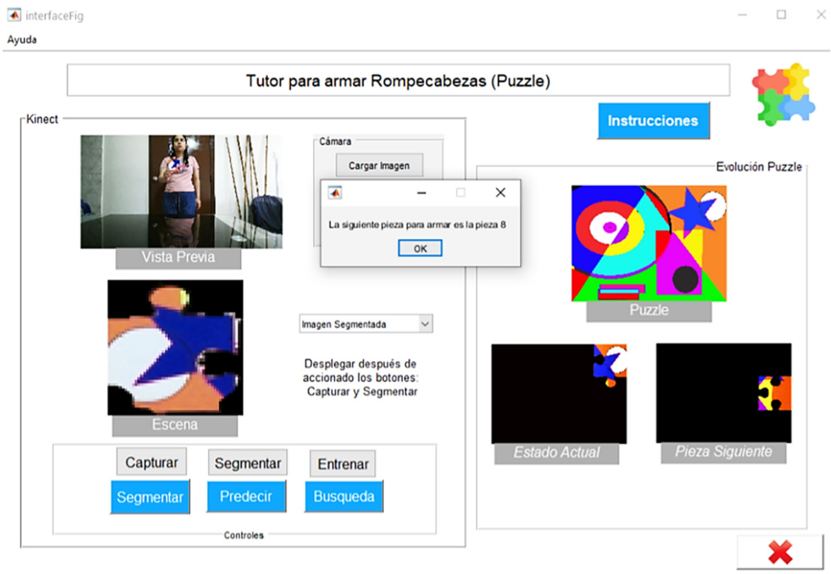

Fig. 10. Graphical interface in MatLab software

5 Discussion and Conclusions

Throughout the development of this work, were addressed two main challenges, the first one was the creation of image database by the using of augmented data as a mixture of real images at different illumination levels and images under artificial noise [22,23]. Therefore, the decision making algorithm based on uninformed search was also a challenge, it was because the requirement of being flexible to fit the size of a general puzzle, for this problem, a 12-piece search problem.

Therefore, the decision making algorithm based on uninformed search was also a challenge, it because the requirement of being flexible to fit the size of a general puzzle, in this case, a 12-piece search problem.

The use of some artificial intelligence techniques such as neural networks requires an initial knowledge base, in this case it was necessary to develop a data set because the case study is a particular puzzle, however, the possibility of developing an approach to transfer learning is presented as an interesting future job. To evaluate the effects of the initial knowledge level, the developed database is shared.

Since a neural network is configured as the central tool that identifies the piece in space, it is necessary to convert the image as a descriptor. Using an image as a descriptor is impractical. PCA algorithm is used as a powerful tool that allows projecting the image as a lightweight descriptor, impacting in the reduction of the training time of the neural network. The descriptor dimension is defined in 30 components because this value ensures a breaking point where the variations of a greater number of components is not meaningful (see Fig. 7). This stage ensures acceptable convergence times for intermediate performance hardware.

According to the network topology used, different levels of error and accuracy are generated. The network that generates more precision and a lower error rate is desirable. It is observed that the performance of the network is not directly proportional to the number of neurons in the inner layer, so it is necessary to carry out experimental tests to validate the selection of the topology. Implementing a confusion matrix is a useful tool for evaluating the performance of work methodologies that is based on a large number of tests that integrate random components, in this case light variations or noise of different types.

Identifying the piece in space is a complex task since it is the piece that moves in space, however the proposed image processing methodology manages to properly capture the piece's information, and with artificial intelligence tools it is possible to identify the piece at software level, to allow decision making.

In the case study presented in this research, the results suggest that the system reachs of the main objective "to put the puzzle together" as well as the natural assembly process. However, it has the potential to solve more complex problems where the conventional process is limited, given this case, the presented system takes a competitive advantage in the assembly process. Another interesting aspect in which the proposed system becomes relevant focuses on populations of people with limitations related to cognitive abilities. To validate this hypothesis, it is necessary to carry out the technological transfer of the proposed system to this type of population and with experts in the areas of cognitive learning to validate it. The presented research is developed in MATLAB, this suggests that the presented development has the potential to be improved in terms of execution time if it is developed in c++.

References

1. Bloom, B.S.: The 2 sigma problem: the search for methods of group instruction as effective as one-to-one tutoring. Educ. Res. **13**(6), 4–16 (1984). https://doi.org/10.3102/0013189X013006004
2. Gao, Y., Barendregt, W., Obaid, M., Castellano, G.: When robot personalisation does not help: insights from a robot-supported learning study. In: RO-MAN 2018–27th IEEE International Symposium on Robot and Human Interactive Communication, pp. 705–712 (2018). https://doi.org/10.1109/ROMAN.2018.8525832
3. Essa, A., Laster, S.: Bloom's 2 sigma problem and data-driven approaches for improving student success. In: The First Year of College: Research, Theory, and Practice on Improving the Student Experience and Increasing Retention, pp. 212–246. Cambridge University Press (2017). https://doi.org/10.1017/9781316811764.009

4. Zaga, C., Zaga, C., Lohse, M., Truong, K.P., Evers, V.: The effect of a robot's social character on children's task engagement: peer versus tutor. In: Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 9388 LNCS, pp. 704–713 (2015). https://doi.org/10.1007/978-3-319-25554-5_70
5. Kolomaznik, M., Sullivan, M., Vyvyan, K.: Can virtual reality engage students with teamwork. Int. J. Innov. Sci. Math. Educ. **25**(4), 32–44 (2017)
6. Nourbakhsh, I.R., Sycara, K., Koes, M., Yong, M., Lewis, M., Burion, S.: Human-robot teaming for search and Rescue. In: IEEE Pervasive Computing, vol. 4, no. 1, pp. 72–77 (2005). https://doi.org/10.1109/MPRV.2005.13
7. Murphy, R.R.: Human-robot interaction in rescue robotics. IEEE Trans. Syst. Man Cybern. Part C: Appl. Rev. **34**(2), 138–153 (2004). https://doi.org/10.1109/TSMCC.2004.826267
8. Levitt, T.S., Lawton, D.T.: Qualitative navigation for mobile robots. Artif. Intell. **44**(3), 305–360 (1990). https://doi.org/10.1016/0004-3702(90)90027-W
9. Shaik, K.B., Ganesan, P., Kalist, V., Sathish, B.S., Jenitha, J.M.M.: Comparative study of skin color detection and segmentation in HSV and YCbCr color space. Procedia Comput. Sci. **57**, 41–48 (2015). https://doi.org/10.1016/j.procs.2015.07.362
10. Norvig, P., Russell, S.: Artificial Intelligence: A Modern Approach, 4th edn., pp. 76–84. Pearson, Hoboken (2003)
11. Rusu, R.B., Cousins, S.: 3D is here: point Cloud Library (PCL). In: Proceedings - IEEE International Conference on Robotics and Automation (2011). https://doi.org/10.1109/ICRA.2011.5980567
12. Khoshelham, K., Elberink, S.O.: Accuracy and resolution of kinect depth data for indoor mapping applications. Sensors **12**(2), 1437–1454 (2012)
13. Sung, J., Ponce, C., Selman, B., Saxena, A.: Unstructured human activity detection from RGBD images. In: Proceedings - IEEE International Conference on Robotics and Automation, pp. 842–849 (2012). https://doi.org/10.1109/ICRA.2012.6224591
14. Welk, A., et al.: Computer-assisted learning and simulation lab with 40 DentSim units. Int. J. Comput. Dentistry, **11**(1), 17–40. (2008). ISSN: 14634201 2–s2.0-49049085467
15. Zheng, J., Cao, X., Lin, Y., Zhang, J., Feng, X.: An introduction of DentSim in pre-clinical dental training and practice. Shanghai kou qiang yi xue - Shanghai J. Stomatol. **23**(6), 749–754 (2014)
16. Fletcher, J.D.: The value of digital tutoring and accelerated expertise for military veterans. Educ. Technol. Res. Dev. **65**(3), 679–698 (2017). https://doi.org/10.1007/s11423-016-9504-z
17. Woods, K.: The development and design of an interactive digital training resource for personal tutors. Front. Educ. **5**, 100 (2020) https://doi.org/10.3389/feduc.2020.00100
18. Suebnukarn, S., Haddawy, P.: A collaborative intelligent tutoring system for medical problem-based learning. International Conference on Intelligent User Interfaces, Proceedings IUI, pp. 14–21 (2004) https://doi.org/10.1145/964445.964447
19. Noble, D.D.: The classroom arsenal: military research, information technology and public education. The Classroom Arsenal: Military Research, Information Technology and Public Education, pp. 1–224 (2017) https://doi.org/10.4324/9780203730317
20. Ventura, M., et al.: Preliminary evaluations of a dialogue-based digital tutor. In: Penstein Rosé, C., et al. (eds.) AIED 2018. LNCS (LNAI), vol. 10948, pp. 480–483. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-93846-2_90

21. Noonan, R.: STEM Jobs: 2017 Update. ESA Issue Brief# 02–17. US Department of Commerce (2017)
22. Ding, X., Hu, R.: Learning To see faces in the dark. In: 2020 IEEE International Conference on Multimedia and Expo (ICME), London, United Kingdom, pp. 1–6 (2020) https://doi.org/10.1109/ICME46284.2020.9102816
23. Zhang, Y., et al.: A poisson-gaussian denoising dataset with real fluorescence microscopy images. In: 2019 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), Long Beach, CA, USA, pp. 11702–11710 (2019) https://doi.org/10.1109/CVPR.2019.01198