Finger Pointer Based Human Machine Interaction for Selected Quality Checks of Industrial Work Pieces

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Abstract

Interaction between humans and machines, especially robots becomes more and more important in industrial production and quality managing processes. We developed a demonstrator system for selected quality checks of industrial work pieces using a special kind of human gesture, the finger pointer, for the communication with the robot-guided measurement system. The demonstrator consists of two optical 3D scanners, a six-axis-robot (mounted on a mobile platform) and a master system (PC and the necessary software modules which realises the communication between the components). The interaction between the human and the machine is realized using the so-called interaction sensor, which is one of the optical 3D scanners. The main feature of this scanner is the detection of the position on the surface of a work piece where the humans finger points to. The robust results of the pointer location determination show a good fitting for the application of the demonstrator system for selected quality checks of industrial work pieces.

1 Introduction

Interaction between humans and machines, especially robots becomes more and more important in industrial production and quality managing processes as well as in scientific research, medicine, and social life. This interaction often consists of orders of the human to control the robot or the machine.

Human robot interaction (HRI) requires a high measure of communication, namely the exchange of signals and information. The kind of these signals depends on many aspects such as the ability of the partners to send and detect the signals and the environment of the information exchange. Typical kinds are visual and acoustic signals which differ, of course, depending of the direction from machine to human or vice versa. Visual signals from the human to the machine are often gestures which are detected by cameras. Hence detection of gestures [1] and especially gestures of the hand [2] has important significance to HRI and human machine interaction (HMI). Consequently, human-robot interaction and human-machine interaction are current objects of research, especially for the last 20 years (see [3, 4, 5, 6]).

For industrial quality control and management often automatically generated 2D or 3D measurements of the products are processed. However, every certain object has a complex geometry and complete 3D measurement and/or the planning of the measurement task may be too effortful and time consuming within 3D-measurement machines preventing a permanent automated check of certain work pieces. On the other hand, human is very clever concerning being aware of the necessity to check because he immediately sees that something may be wrong with the object. So it may be more efficient to let the human decide which object must be checked and at which region. So the goal of our project was the human driven selection of the necessary area of inspection and the consecutive automated assignment and realization of a quality check (here 3D surface measurement) by a robot-guided measurement system. The result of the checking procedure may be used for evaluation but is outside the scope of this work.

Our project which will be described more detailed in the following mainly uses a special kind of human gesture, the finger pointer, for the communication with the robot-guided measurement system. Gesture detection and interpretation recently has been a major field of research [6], and hand gesture [2] and especially finger pointer detection [7] is a special one in this field.

Nickel and Stiefelhagen [8] introduce a tracking system based on 2D colour images which realizes classification of both hands' trajectories by means of previously trained pointing gestures based on Hidden Markov Models. Lai et al. describe a HRI system where human shows a mobile robot a path to drive. For detection of the finger pointer 3D data from a Kinect and 2D colour images are combined to extract the skeleton of the human. Pointing direction yields from a direction in 3D from shoulder to the pointing hand. Azari et al. [9] also introduce a system for mobile robot navigation using 2D colour images and convolutional neural networks. Pointing direction is here determined by the detected face and hand of the human. Liu et al. [10] describe the finger pointer as one of several hand gestures which can be distinguished in 2D colour images.

In our work we developed a very special finger pointer interpretation with the aim of localization of the checking area on a work piece. For this we used a 3D stereo scanner based on structured light projection technique in the near infrared range [11]. For our finger pointer detection algorithm, we relinquish on detecting certain body parts but and assumed only arm, hand, and fingers occurring in the considered active part of the 3D space.

2 Description of the demonstrator

We developed a demonstrator system for selected quality checks of industrial work pieces such as car body parts (e.g. doors), pressed sheet metal parts, or castings made of metal or plastics.
Our demonstrator system for the selected quality check of industrial work pieces consists of: two optical 3D scanners; a six-axis-robot including control (mounted on a mobile platform); a master system (PC and the necessary software modules which realises the communication between the components). The functions of the two 3D scanners are the following. The first scanner, called interaction sensor (IAS) is responsible for the detection of the checking area by detecting the finger pointing direction and the second one, the so called check scanner (CS), must realize the 3D measurement with high accuracy. Check scanner can be chosen according the special checking task and is therefore changeable. **Figure 1** shows the demonstrator with the robot and the two optical scanners. The mobile platform under the metal plate serves to bring the demonstrator to the operating site in the industrial environment. It is not yet part of the demonstrator itself. However, this can happen later by inclusion of the mobile platform's movements into the interactive steering process caused by the finger pointer.

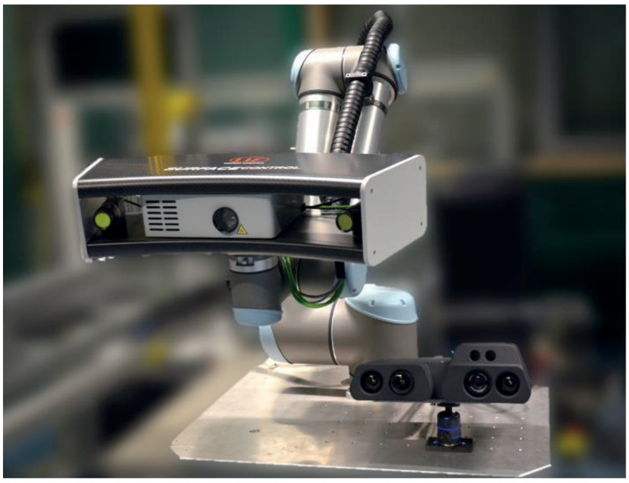

Figure 1 Demonstrator system

The main novelty of our system is the adaptive usage of the quality check function activated after order by the human supervisor. The advantage of the rare processing of the check procedure is to work efficiently without delay in the production process. Here the advantageous ability of the human to recognize and capture complex situations is applied.
The focus of this work will be addressed to the human machine interaction function of the IAS. The main processing steps of the demonstrator system include detection of checking necessity (signal by a human user), determination of the 3D pointer position, calculation of the necessary position and orientation of the checking 3D sensor, bringing the checking 3D sensor into this position by the gripper arm of the six-axis-robot, and performing and evaluating the checking 3D measurement.

The final step of the interaction task is the evaluation of the check measurement by the human supervisor. According to the work piece this may be a good/bad classification or a decision concerning a necessary revision of the work piece.
The main content of this work is the description of how the two items check measurement initialization and detection of the measurement position are realized. Both tasks were realized by detection and interpretation of a finger pointer of the human supervisor using an optical 3D scanner based on structured light illumination in near infrared range (NIR). This scanner is called here interaction sensor (IAS).

3 Interaction sensor and finger pointer detection

The main component of the demonstrator system for solving the human machine interaction task is the interaction sensor. Hence, it should be described here in detail.

3.1 The interaction sensor (IAS)

The 3D interaction sensor consists of a stereo camera pair in infrared range (IR), a projection unit for production of structured patterns in the IR, a colour camera (in visible light range), and the necessary electronic and mechanical parts. It covers a volume of about 800 x 800 x 500 mm³ and records 2D images with 360 fps. Frame rate of 3D point clouds is about 30 Hz. This means, IAS generates continuously 3D surface data of the observed scene. Spatial resolution in the object space is approximately 1 mm. **Figure 2** shows the IAS.

Figure 2 The IAS

The measurement principle of the IAS can be described as follows. The projection unit illuminates the scene with structured patterns continuously generated by a GOBO-wheel [12] in the infrared range. Hence, no irritation can occur, if the human looks to the object or to the sensor. In our system we used sequences of aperiodic sinusoidal fringe patterns [12] for illumination. Both cameras are calibrated a-priori in order to know the geometric relation between them. The cameras synchronously record image sequences of the illuminated scene. Sequences of ten consecutive single images are used to calculate corresponding points in both cameras which can be used together with calibration data to calculate the 3D position of the object observed points. This is done by triangulation of corresponding image points (see e.g. [13]).

3.2 Interaction tasks

The first interaction task between human and demonstrator system consists of the signal of the human, that check procedure is necessary and the localization of the check position. After starting the demonstrator system, the IAS observes the scene showing the object by continuous 3D measurements. Initially, a 3D surface model of the scene is produced under the assumption of absence of humans or other things except the object in the scene. Then, if the user detects a place or an area on the object which should be checked, he shows to this position by finger pointer (**Figure 3**). Subsequently, the detection algorithm of the IAS determines this position and sends the 3D coordinates to the robot. Afterwards, the robot brings the checking sensor into the best position according to the detected area to be considered.

3.2.1 Finger pointer localization

After starting the system IAS records 3D data continuously in the current measurement volume. If no person crosses the field of view, 3D data of the scene are captured, namely the work piece and eventually the background including brackets or mountings. After a certain time, these data are merged to the 3D reference scene model (RSM). Many recordings ensure a relative completeness and averaging reduces noise. This is realized by algorithm A0. RSM may be improved using the CAD model of the work piece if available.

Figure 3 Human shows to the check position by finger pointer

Regarding to the finger pointer localization task the system has four different states, namely

- ST0: produce RSM
- ST1: waiting for finger pointer
- ST2: get arm points
- ST3: determine check position
- S4T: check position calculated

Continued 3D data recording and subtraction of RSM leads to 3D point clouds of objects entering the measurement volume. If this object is a person with a pointing arm and finger, this will be detected by the implemented algorithm A1 of the IAS. This algorithm counts the 3D points not belonging to the RSM. If the number exceed a threshold, state changes from ST1 to ST2 (determine check position).

In state ST2 difference point cloud DPC is permanently generated and analysed. Algorithm A2 detects, if DPC has reached a certain size and does not change significantly. Next step is the determination of the check position. This is realized by algorithm A3. Input for A3 is the DPC. First, the arm is segmented (**Figure 4**). From the segmented arm, the main direction d_m is yielded by principal component analysis (see [14]). With the help of d_m and other thresholds, the 3D finger points can be extracted. Application of principal component analysis again yields the pointing direction d_p which can be intersected with the surface points of the work piece leading to the 3D check point p_c and achieving state ST4. Both vectors d_p and p_c can be returned to the master system, which can control the robot for its optimal position for the check measurement. Table 1 collects the steps of algorithms A0, A1, A2, and A3.

Table 1 algorithmic steps from process start to detected check position

Algorithm	Steps
A0	Precondition: system in state ST0 a) Continuous data acquisition, calculation 3D point cloud b) Analysis of spatial distribution of 3D points: more than ten consecutive datasets very similar? Yes: goto c) No: goto a) c) Generate reference surface model RSM of the background including work piece, change to ST1
A1	Precondition: system in state ST1 d) Continuous data acquisition (APC), calculation difference 3D point cloud: DPC = APC – RSM e) If more than ten consecutive datasets DPC contain more than *thr* 3D points? Yes: change to ST2, goto A2 f) No: goto d)
A2	Precondition: system in state ST2 f) Continuous generation of human 3D surface model (arm) ASM from DPC g) Analysis of ASM: are more than ten consecutive datasets very similar? Yes: change to ST3, goto A3 h) No: goto f)
A3	Precondition: system in state ST3 h) Get arm direction d_m of ASM data by PCA i) Get finger segmentation (FS) by point cloud analysis along d_m j) Apply PCA to FS and get finger pointing direction d_p, intersect d_p with surface of RSM and get check position $p_c = (x_c, y_c, z_c)$, change to ST4

Figure 4 Segmented arm and finger and detected check position on target

3.2.2 Robot reaction

If check position is transferred to the master system, path planning for the robot action is started. This includes both best orientation of the check measurement sensor according to the work piece under consideration of the physical restrictions of the robot and the optimal movement of the robot's axis in order to reach this orientation. Here, self-collisions of the robot (including the sensor on its arm) must avoided.
From the best position check sensor takes images and captures 3D data of the work piece (**Figure 5**).
The data of the 3D measurement are sent to the master system, and an analysis software evaluates the measurement result. Subsequently, a decision concerning the next necessary action of the system or the human supervisor must be made. This decision may be acceptance or rejection of the work piece, repetition of the check measurement, or other action.

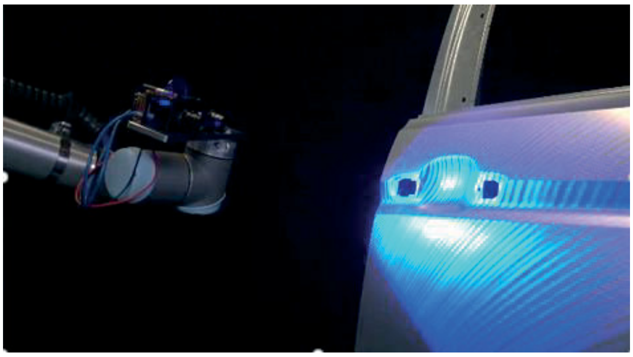

Figure 5 Check measurement with structured illumination (in visible range) by the CS mounted on the robot's arm

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4 Experiments and results

For evaluation of the developed algorithm a series of experiments was performed. The first experiment was for determination of the thresholds and the necessary time for getting the check position. Typically, at least five consecutive 3D datasets including the hand with pointing finger were necessary to fix the pointing position. The time to get the was always about one second.
Next series of experiments concerned the reproducibility of the pointed position. In order to get realistic values, three persons performed the pointing to the same target from varying distances (about 50 mm, 100 mm, and 200 mm) to the object using both left and right hand for pointing at corresponding standpoints (left to the object using left finger and right to the object using right finger). Each pointing process was repeated 20 times. If pointing position could not be found, pointing procedure was repeated. All in all, 360 successful pointing processes were performed.
The numbers of not successful trial were one at 50 mm, two at 100 mm, and six at 200 mm distance between finger top and measurement object. Hence, the rate of successful pointing processes can be estimated as 95 % (200 mm), 98 % (100 mm), and 99 % (50 mm). However, this rate also depends on the carefulness of the pointing person. If the finger pointer is performed too sloppy, correct localization of the check position decreases.
Table 2 shows the average values for the detected check positions $(x,y,z)_i$ and standard deviations (euklidean) depending on person *Pers* and standpoint *i* (left or right) of the person. Table 3 shows the average values for the detected target positions $(x,y,z)_i$ and standard deviations (euklidean) depending on distance *Dist* to the object and standpoint (left or right). Given the average values for standard deviations (SD_l and SD_r) for left and right position.

Table 2 average values for target position detection depending on persons and standpoint

Pers	$(x,y,z)_l$ [mm]	SD_l [mm]	$(x,y,z)_r$ [mm]	SD_r [mm]
A	220,154,1338	13.2	188,157,1342	10.0
B	223,166,1341	11.9	206,144,1336	11.2
C	219,138,1333	9.8	209,147,1336	9.5
Mean	221,153,1337	11.6	201,149,1338	10.2

Table 3 average values for target position detection depending on finger distance and standpoint

Dist	$(x,y,z)_l$ [mm]	SD_l [mm]	$(x,y,z)_r$ [mm]	SD_r [mm]
50	219,142,1334	7.7	199,142,1336	5.0
100	225,154,1337	11.5	200,148,1336	11.2
200	217,162,1341	15.3	204,158,1340	14.4
Mean	221,153,1337	11.5	201,149,1338	9.9

True marker position was at x = 216 mm, y = 151 mm, z = 1337 mm. As it can be seen, significant differences occur between left and right hand usage for pointing (x-coordinate person A and *mean*, y-coordinate person B) and also significant differences occur between the distances (drift of

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y-coordinate). Variance of the localization increases by distance to the target as expected.

Figures 6, 7, and **8** show the distribution of the detected pointing position on the target object (*x*- and *y*-coordinate) for each single pointing process of the three persons. The true marker position is in the centre of the drawn coordinate system.

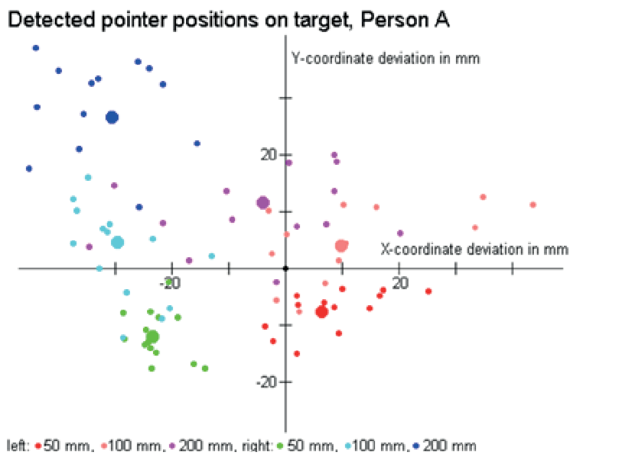

Figure 6 Detected pointing position on target of person A

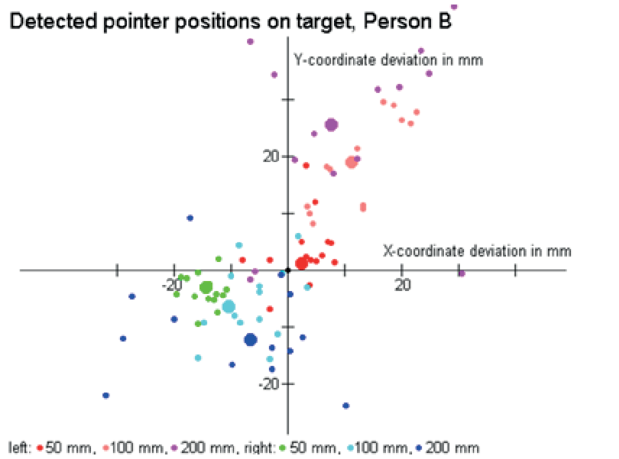

Figure 7 Detected pointing position on target of person B

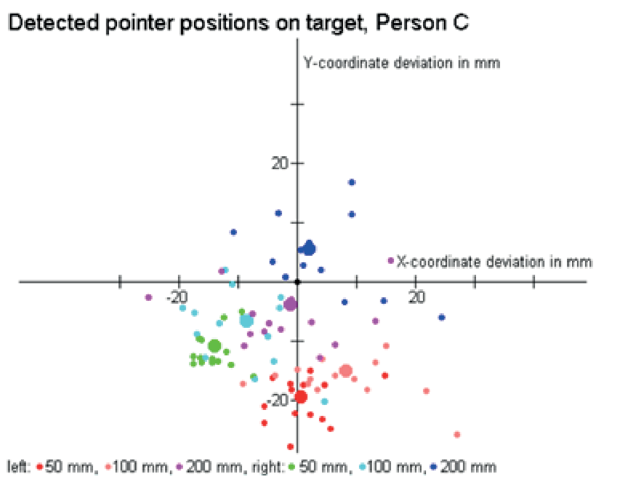

Figure 8 Detected pointing position on target of person C

Origins for the strong systematic spreading of the values and the systematic differences between persons, showing directions, and target distances may be the individual finger form and size, the stretching of the finger at pointing process in combination with the algorithm of 3D point assignment to the finger, and the angle between the finger and thee object surface. Biggest spreading of detected target position of person A may be, e.g., due to the shorter length of the finger compared to those of persons B and C. Additional random spreading is due to finger vibrations and distribution of the detected 3D points (not the complete finger is captured).

For comparison, check position was also determined using a hand-held laser pointer (**Figure 9**). Here, check position localization doesn't require the human very close to the working piece. Some applications may require such a longer distance, e.g. when the object has a high temperature or if it too dangerous to come too close. Laser pointer localization was realized using the colour camera of the IAS and 2D difference image processing to the previous image without laser spot.

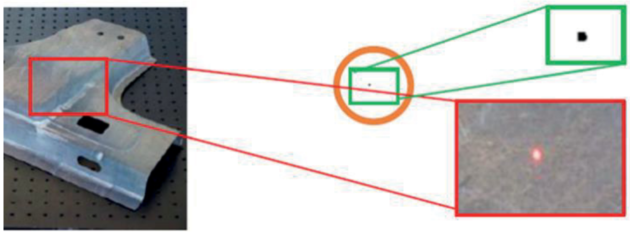

Figure 9 Localization of check position using a laser pointer and 2D colour camera

The reproducibility of the laser pointer based localization was in the same range as the finger pointer based, whereas the distance to the object was much longer (> 2 m).

The results show a good robustness and sufficient reproducibility of the measurements. As it is seen, repeated localizations can at most deviate by some centimetres. Hence check measurement should be performed observing a region of suitable size.

5 Discussion

The experimental results show the suitability of finger pointer for the purpose of detection and localization of a certain position on a target. The capturing of the 3D data of the showing person was realized by means of a structured light based 3D stereo scanner working in the NIR. The suitability for application in the content of a human machine interaction within a demonstrator system for selected quality checks of industrial work pieces has shown. The algorithm for finger pointer localization uses certain restrictions which help to make the finger pointer detection and localization of the pointing area very robust. These restrictions are

- Known background (i.e. the region of the pointing target)

- Assumption of a human arm as the content of the point cloud to be processed
- Known distances and restricted working space (limitation of the measurement volume)

Making use of these preconditions the process of localization of the pointing area gives a precise target position in a range of about ± 30 mm. For the presented application of a collaborating checking system demonstrator this precision is absolutely sufficient. However, if the finger pointer procedure should be used in other applications, especially for guiding robots or identification of several objects, the features of the demonstrator system should be changed towards larger observed regions and connection with detection of skeleton features of the human. Additionally, connected with gesture detection procedures, the algorithm may support existing gesture interpretation applications.

6 Summary and outlook

A new finger pointer detection algorithm was presented for localization of target positions on arbitrary objects (e.g. work pieces). It has been successfully applied in a demonstrator of a collaborating checking system. The new algorithm gives robust and accurate results and terminates in acceptable time.
Future work should be addressed to the following items:

- Increase of the active volume of the IAS
- Connection with external segmentation modules in order to apply the algorithm also to scenes with complete moving persons
- Connection of the 3D data with 2D video-streams

Future work should also include more experiments concerning other hand gestures.
Additionally, this kind of interaction task may be also used for menu selection by finger pointer using a menu projection to a wall or a screen.
The interaction between human and robot should be extended to the involvement of the mobile robot platform to the demonstrator system. If a larger inspection area can be covered by the IAS, the robot may process in a larger region which can be obtained by an interactive control of the mobile platform, too.

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