Data Acquisition in Cast Iron Foundries by Image Analysis

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Abstract: The project IDA - **I**ntelligent **D**ata **A**cquisition is an interdisciplinary project in the fields of applied informatics and mechanical engineering. Its purpose is to collect process relevant information in industrial foundry processes like iron casting with handmade and mechanically made molds. Currently a lot of data sets are collected by hand. But these contain inaccuracies and errors and are not available digitally for further analysis. As a result it is not possible to evaluate them automatically. In particular it is not possible to conclude from a defect cast part to the whole set of its production parameters. We develop several procedures to collect these data sets and prepare them for computation in data analysis algorithms. The acquisition of digitally available data in IDA is done mostly by optical sensors. In this paper we describe our approach especially regarding marking and recognition of relevant objects. Furthermore we show first results in environments close to reality.

1 INTRODUCTION

In foundries the main problems in data acquisition are missing continuity in the manufacturing processes and difficult environmental conditions, for example high temperatures above 1300 degree Celsius. As an obvious result it is for example not possible to work with transmitters like RFID tags. The operating range for common RFID tags is up to 200 degree Celsius, (Nicholson and Monahan, 1999). Other problems like difficult lighting conditions, air contamination and colorless elements complicate the data acquisition by optical sensors, some of them are shown in Figure 1.

Figure 1: Air contamination and difficult light conditions during furnace tapping.

During the first project phase we analyzed the existing processes and identified the main reasons of faulty parts. From common knowledge about foundry processes we then gathered the different pieces of data, which are necessary to identify the circumstances leading to the errors. Different procedures must be implemented to collect the necessary data mostly with digital image processing operations. At this stage one main subject has been identified: Mapping of cast parts and sand cores to their date of casting respectively their use in a mold. This mapping is essential for an assignment of faulty parts to the parameters of the casting process.

In the following section we want to motivate research investigation in foundries. After that we describe the approach of our project and the current state of two main subjects in our project, especially object identification (tracking). The comparison with related work in industrial research will be done in the subsections because the relevant research activities are quite distinct for our different subjects. Finally, we will give an overview of our achievements and an outlook to further work.

1.1 Economic Dependency

Resources needed for production of cast parts are mostly imported, like pig iron or coal. Other important components are the seldom earth elements (SEE) like Cerium or Bismuth. These elements are necessary to influence the metallurgical structure of the cast iron. For the extraction of these SEE strong economically hazardous procedures are exercised.

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Main exporter of SEE is China, according to a recent study the annual demand of SEE remains constant, but the export rate of China decreased in the last years. This is shown in Figure 2, an evaluation of "Statista", about the consumption of SEE.

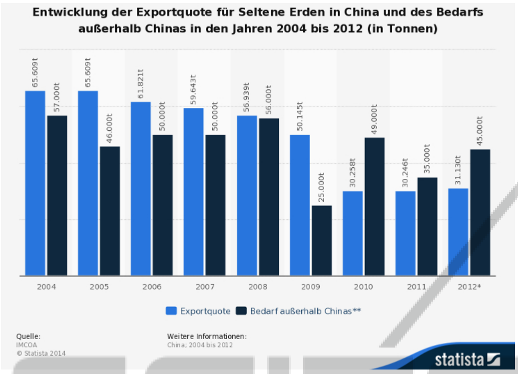

Figure 2: Evaluation about the SEE consumption toward the export value of China - the main exporter of SEE.

The low export rate since 2011 led to increasing prices for the raw materials as described in Figure 3. This trend was very difficult for the German foundry branch. Since the last years the price fluctuation is also occurred from the stock exchange.

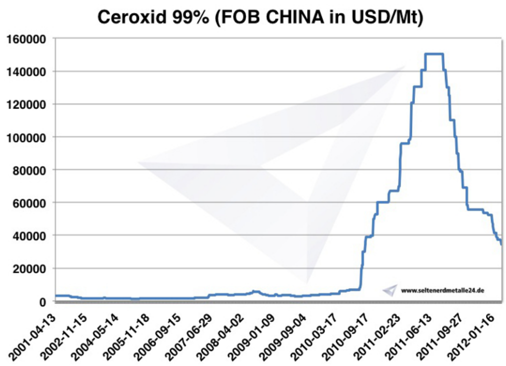

Figure 3: Cost trend of SEE in the last years.

2 PROJECT DESCRIPTION

The research project IDA develops new ways to combine existing iron casting processes with modern image processing operations to collect process specific information. There are no existing procedures to collect such information yet, at least in medium sized foundries. The main target is to record data sets which are currently not collectable. With these data sets it will be possible in the future to make predictions of the cast part during the running production process. An early intervention is possible and can reduce scrap. However, the creation of the described predictions is not subject of IDA. These were developed in an earlier research project, (D. Hartmann, 2014).

2.1 Process Analysis

As described in Section 1 it is possible to make qualitative forecasts about a cast part, if data sets of the casting process are available. However, different casting processes must be analyzed separately. Most of the problems can be found in middle class foundries.

In IDA we work with three foundries and we evaluated the individual data situation of each project partner. Each foundry has been analyzed concerning their current data acquisition. It could be found that the data situation strongly depends on the different production processes. Foundries that produce high-volume use molding machines that provide a good data situation, but it is difficult to assign the given data to an individual cast part or to a casting defect as mentioned before.

However, in low-volume foundries which produce with handmade molds the identification of cast parts is not problematic, but the processes depend on the situation and can change during the production and data acquisition is mostly not realized at the moment. To improve the general data situation it is necessary to collect additional data sets and improve the data assignment. These data sets can be categorized by the following keywords:

- Cast part marker
- Sand core identification
- The way of melt
- Optical character recognition
- Cast spurt monitoring
- Flask layout

The main area of research in cast iron foundries was the metallurgical properties. Whereby most of the usable data sets come from the spectral analysis of the melt, and the mechanical properties like impact strength or tensile strength. Data correlations between the sand core and the mold and their influences for an individual cast part cannot be rated at the moment. Professional literature describes the high influence rate of the molding sand to the cast part errors. Values more than 70% are described in (Gagne, 2004) at page 87.

2.2 Acquisition Methods

Error causes have been identified for the development of the acquisition methods. For the data acquisition new procedures were established who are capable to integrate into the foundry process. To collect the image data different camera types are necessary to collect the image data:

- Industrial Cameras are used for:
  - Cast part identification
  - Object detection and tracking
  - Optical character recognition
- Thermal image cameras are used for:
  - Temperature detection
  - Slag detection
  - Fill level detection

The data transfer can be realized by a local area network. For smaller data sets it is also possible to use a wireless network. The data transfer in wireless networks is not affected by the electromagnetic emission. Nowadays temperature measuring lances work with wireless LAN in front of the furnace.

3 CURRENT STATE

Based on decisions about platform independency, availability and real time usage, the test application is developed in Qt using C++. For common image processing operations OpenCV is used. The graphical user interface is developed as a debug and monitoring tool. The implementation of data interfaces is not planed by IDA but can be done in the future.

To simplify the implementation we decided to define different modules. Every module works as an own workflow and can be started and managed from the graphical user interface. The user can decide which module should be observed and can interact with it.

The combination of these modules can change by the field of application. A foundry with mold machines can define other module constellations than a foundry with hand made molds.

3.1 Individual Marker Detection

The implementation of individual marker detection was developed to solve the individualization of the production of cast parts in molding machines. This is also demanded by the automotive industry, leading to cast parts with a complete traceability, (Clemens, 2008). During the implementation and further analysis of the marker elements another field of application could be found with the labelling of ladles and molds.

3.1.1 Recent Work

Several different ways are available for the marking of castings. Most of them are very expensive or not precise enough. The availability of procedures depends also on the cast way. Handmade forms can be labeled with pre-made numbers that are inserted into the negative form. However, machine made molds can just be marked during the short production process. The list of available marker elements is as short as the corresponding academic literature described in (Wadhwa, 2013).

Cast clocks are not precise enough, because they use one number for a specified time span. In the professional journal ”Giesserei”, the University Harz presents an innovative cast clock (Meissner, 2011) but the device cannot be integrated into a molding machine because of the relatively big control unit. Whereby the procedure with laser marker can be done precise enough, but the devices are too expensive (Meissner, 2011).

The United States Patent (Hovorka, 1996) describes a procedure using an expandable plastic tag and a slot in the cast part. The main problem of this process is the size requirement, also described in 3.1.3. Another problem is that cast parts produced in molding machines cannot be marked in the order they are produced. The plastic tag must be inserted to the cast part by hand but they travel a long distance in the automatical molding machine and overtake each other. At least in the shaker or the sandblaster, which are necessary to release them from the molds. We found that cast parts got a delay of nearly 10 - 15 minutes. By a clock cycle up to 7 seconds the procedure is not exact enough for the data mapping.

The test of the availability of other code elements for example the gray code described in (E.N.Gilbert, 1957) showed that the redundance is absolutely sufficient but the size requirements based on the necessary individual marker elements and the forgeability in cast parts are not suitable. Figure 4 shows a gray code element with 8 different positions. The individual positions are not enough as it has been described in 3.1.2. In our experience it was also not possible to scale them down to our size requirements from 3.1.3.

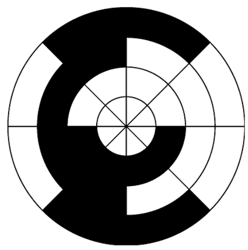

Figure 4: Gray code with 8 positions from (Gray, 1947).

3.1.2 Marker Specific Requirements

The requirements to the representable area are also different. The area for the marker detection depends on the mold machine. At the moment every cast part gets the cast day and the nest number. The cast part can just be identified to the production day and to the nest number. With the current available data sets it is not possible to define exactly which melt was used for the production of a specific part.

Based on these findings, we developed a new code and a corresponding marking element. It is based on currently 6 needles, which can have different orientations. A picture of the marking element in a test scenario is shown in Figure 5. With the new procedure the mold number can be added to the cast part. Every cast part gets an additional identification element and is individual determinable. To test the usage of the marker elements in foundries different test cases were defined. To ensure the usability, six needles are sufficient to mark every cast part in a production charge. With the six needles a maximum count of 4096 individual positions are available. Assumed by a cycle time of 7 seconds nearly 1000 molds can be molded in a charge of 2 hours, without idle time. If more markers are necessary more needles can be added to the marker device. On the current used prototype every needle has 4 positions. The results of an test prototype showed that more positions are not detectable, as described in Section 3.1.8.

3.1.3 Size Requirements

To secure a minimal modification on the cast part and on the molding machine a few specific values must be added. The actual available size on the cast parts is *30mm x 16mm*. The available size for the marker control device depends on the negative mold actually a mold thickness of *40mm* is necessary.

The device is designed to work completely autonomic. No additional connections like external energy supply or a connection to a control device are necessary. Figure 5 shows the test arrangement to controll the marker device.

3.1.4 Detection Procedure

For detection of a cast part the location and interpretation of the needle positions is needed. The detection procedure is separated into different steps, all of them are necessary for a complete rating. Through the following steps the surrounding circles of the needles can be detected with processes like hough transformations. The circles must be rated based on their positions. This process is similar to the described process

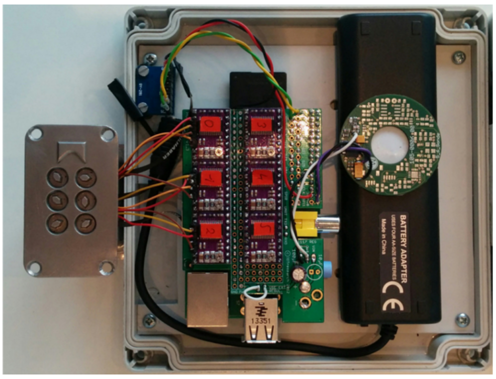

Figure 5: Test arrangement of the marker device. As a motor controller a raspberry Pi was used with a breakout kit.

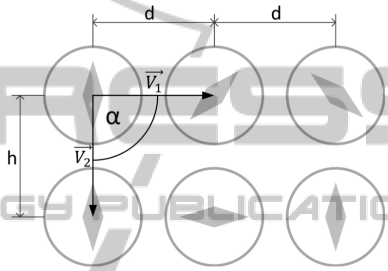

Figure 6: Schematically dimensioning of the marker detection element.

of the traffic sign detection from (Lorsakul, 2007). Difficult light conditions and air contaminations like fog are also comparable problems.

The whole image processing pipeline for this task can be seen in Figure 7.

In the following subsections we will outline our solutions for the different stages above.

3.1.5 Orientation Detection

A position helper element was defined and integrated to the marker device, to detect the position and orientation. But the dimensions of the orientation element was to small, especially with draughts. Figure 8 shows the result of the line detection. It was planned to use the Hough line detection, as described in (Duda and Hart, 1972), and evaluate the detected lines in reference to their orientation and length. But the results are not applicable.

The detection and interpretation of the needles are not affected. The problem is the orientation and classification of the needles, and must be noted in the code interpretation 3.1.9. At the moment two different orientations are possible.

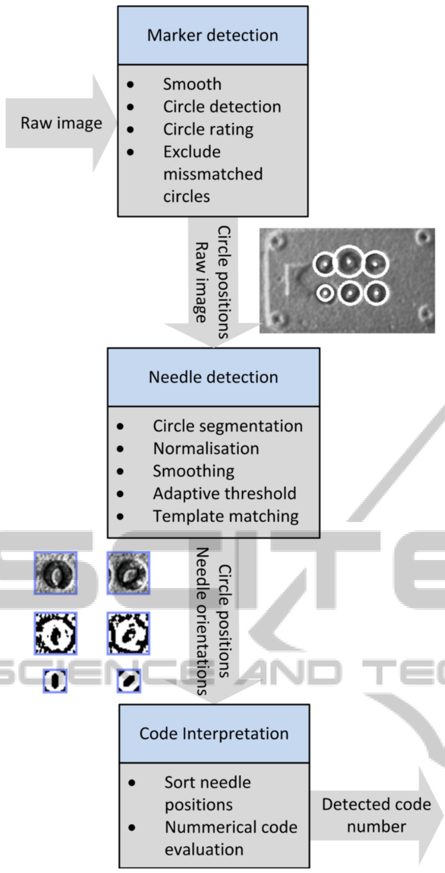

Figure 7: The image processing pipeline of the marker detection procedure.

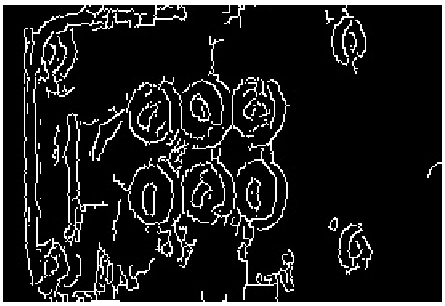

Figure 8: The line detection generates quite good results by the circles, but the orientation helper on the left side can not be detected.

3.1.6 Circle Detection

With the OpenCV method houghCircles it is possible to detect the needle positions. The method offers some parameters like a threshold for the canny edge detector or some circle features as described in (Laganiere, 2011) at page 176. Another influence to the Hough transformation can effect with a Gaussian blur. It is necessary to smooth the structure of the cast part to reduce the mismatches, and improve the quality of the circle detection.

Figure 9 shows the detected circles, in the upper image a lot of wrong circles are detected, the image below was done with the described blur. This effect was described from (Laganiere, 2011) on page 176 and (Lorsakul, 2007). Similar operations are described by (Kimme et al., 1975), in this case the circle detection was improved with thresholding operations.

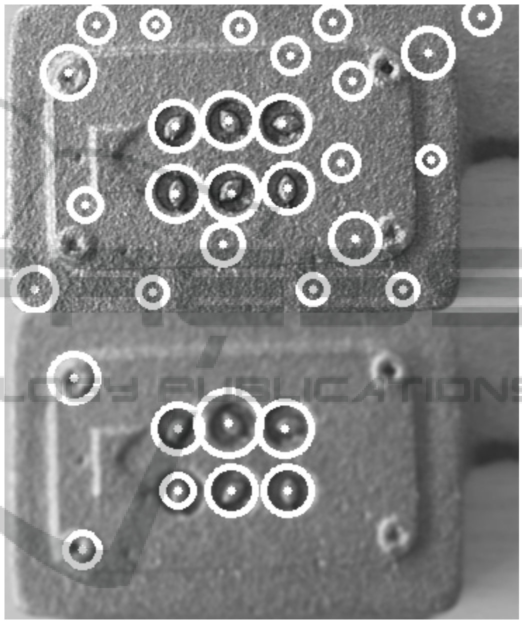

Figure 9: Circle detection: Original grayscaled image - a lot of circles are detected because of the cast part structure, the smoothed image shows just a few mismatches.

If the smooth effect is too much the circle detection does not deliver all needle positions. The marker element can't be detected if too many needles are missing and the circle rating can not be done.

3.1.7 Circle Rating

A cast part can show more circles than given by the marker element. Beside the cast part structure different influences like borehole markers, cast errors and other geometric elements can be detected as mismatches by the circle detection. To handle this situation we developed a procedure based on our geometric properties as described in Figure 6. The first step is to create cluster with circle accumulations. After this preselection all single detected circles lying outside are no longer considered.

In the following procedure we define "used circles". A used circle describes the position of a needle and will be used to make a segmentation of the original image data. The definition of a used circle depends on the dimensioning of the marker detection element. Each circle needs two or three neighbours in a specified distance according to the position. Figure 10 shows the needle position after the building of clusters.

Caused by irregularities of different influences like lightning conditions, cast structure or cast errors the detected center can differ from the real needle position. Affected by these variations it is necessary to define thresholds for the rating.

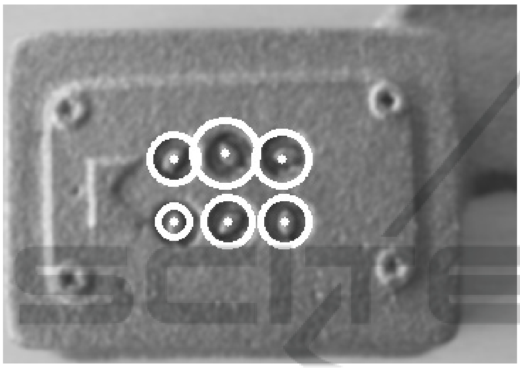

Figure 10: Detected needle positions after the clusterisation procedure.

To ensure that the circles are part of the marker element it is necessary to calculate the distance between them. Another advantage of the arrangement is that the circles are connected with a square angel. The scalar product of the vectors between the neighbours is nearly *0*, because of the before described irregularities.

3.1.8 Needle Identification

The needle identification needs the original image data. The positions of the detected circles from section 3.1.7 indicates the needle positions. These positions are used to create for each needle a segment of the original image. To detect the needle orientation, different matching procedures can be used. Because of irregularities like cast defects and cast structure it is necessary to work with similar image processing operations as described in section 3.1.6. Every needle has 4 predefined positions.

To detect the needle orientation different matching procedures are available, the best results are determined by the template matching with 4 position templates. With more than 6 positions in the given size and in average lighting conditions a lot of miss matches occurred and detecting rate drops below 80%. These errors are attributed to inaccuracies and cast errors, which we will find in realistic environments.

For the template matching it was necessary to define an extraction process to ensure that the influences caused by cast structure, color differences and different light conditions can be minimized. This effect is also described by (Parker, 2011) on page 333.

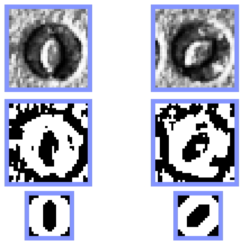

Figure 11: Template for the template matching procedure - the Figure shows the possible orientations $\{0, 1, 2, 3\}$.

The best results of the matching procedure could be determined by the usage of the needle shape. To extract the needle contour of the segmented image we are using different algorithms. The first step is a downscale of the segmented image. This reduces the influences of the cast defects and the cast structure. The normalization increases the contrast of the image and optimizes the differences between the needle and the circle. By a Gaussian blur influences of cast defects and structure can also be minimized.

For shape extraction we are using an adaptive threshold. Threshold methods with an constant value were not sufficient. Furthermore an adaptive threshold is more robust respectively to non uniform illuminations and the background, as described in (Leong and Yue, 2009).

The resulting binarized image contains the shape of the needle and can be used as input for the template matching procedure of OpenCV. Figure 11 shows the different stages for the recognition of needle positions.

With the used test images all needles could be detected. To use the application in real foundry conditions the process we expect that the detection has to be even more robust. The planed improvements are described in section 3.1.11.

3.1.9 Code Interpretation

The marker detection is based on a four number system, as described in section 3.1.2 and 3.1.8. Several standard algorithms are available for the interpretation and can be used for the implementation.

3.1.10 Result

With the implementation of the marker detection were proved that a identification of the marker elements is possible. To ensure the practicability in real world environments additional works must be done. In Section 3.1.11 the next steps for the implementation are described.

The marker device must be improved with an orientation element. The currently used element can not be detected at the moment as described in Section 3.1.5.

3.1.11 Next steps

It is planed to improve the result of the marker detection and minimize error rates. To improve the matching additional procedures like support vector machines can be implemented and tested (Baggio, 2012), another approach would be the identification by keypoints like ORB, as described in (Ethan, 2011). To improve the detectability of the marker the device will receive an new orientation helper. The current problems are described in Section 3.1.5.

3.2 Sand Core Identification

The high influence rate of the molding sand was described in Section 2.1. A lot of cast errors are caused by mold and not by melt. Core breaks, breakouts or gas blows are some of them. But the most cast errors have different influences, (Hasse, 2003) page 4. In many cases it is difficult to determine the real reasons. To simplify the finding of cause-impact coherences it is necessary to merge mold specific information to the cast part. For sand cores this is not possible at the moment. On the other side, sand cores are necessary to shape complex geometric molds.

We investigated in the idea of the identification of a sand core by sand structure like an individual "fingerprint". To test the practicability of image detection processes to identify a simple sand core shape it was necessary to make some different images from different sand cores, this is described in 3.2.2. Figure 12 shows the structure and the shape of a sand core.

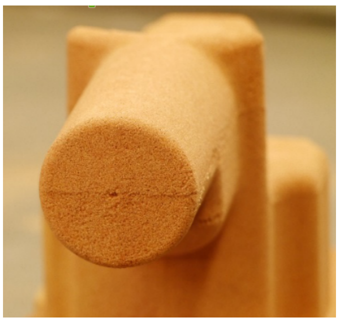

Figure 12: Sand core with simple shape and sand structure.

3.2.1 Recent Work

To the best of our knowledge, no one has investigated in the identification of sand cores as we could not find similar research work.

However, general matching procedures like keypoint detection and matching or template matching procedures are available and approved. For example the ORB keypoint detection, described in (Ethan, 2011), can be used for the detection tests. The detection process with ORB keypoints is quite faster, and free to use instead of SIFT and SURF (Ethan, 2011).

3.2.2 Test Setup

With the first test it was planned to show that every core is individual and distinguishable, and can be detected from other sand cores. The test area was about 50 different sand cores, with a pre-defined distance from the camera. This reduces influences to the matching result, for example scale variances.

Every circle element with the sand core structure was segmented from the image. The segmented image is used to test different image processing procedures with the original images. Every segmented circle is matched with all sand cores. That means we could match 50 segmented images with 50 original images. And got an matching pool of 2500 posibilities for our evaluation.

For the matching procedure we defined different algorithms. First of all we tested an template matching. But the problem was the rotation as described in Section 3.2.3.

All segmented images could be detected, but the main problem of the template matching procedure is that the results are highly influenced of the orientation of the original sand core.

The second tested procedure was a key point detection using ORB keypoints, described in (Ethan, 2011). Figure 13 shows the result of the matching procedure.

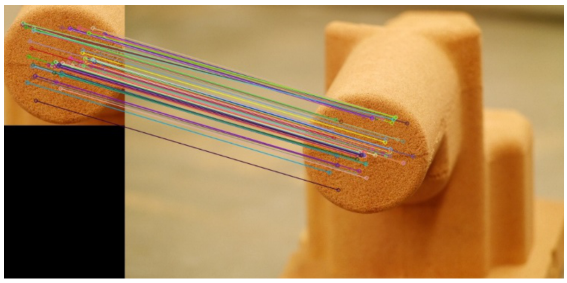

Figure 13: Keypoint detection procedure with correct match.

The results to distinguish sand cores by their individual structure are quite good, all cores could be identified. But the evaluation of the keypoint detection shows similar problems as the template matching. Rotation and scale variances have a highly influence rate to the matching process.

3.2.3 Result

In the foundry the matching procedures can not be used at the moment. The sand cores pass through a long way between the production and the assembly to the mold. On the whole way the orientation of the sand core can not be defined and the distance of the camera can change.

However we could show that the sand cores are distinguishable. In Section 3.2.4 we suggest some additional procedures for continue works on the sand core identification.

3.2.4 Next Steps

To improve the identification rate of the sand cores additional physical notches can be added to the sand cores to simplify the orientation detection of the sand cores. Another approach can be done by object detection. The shape of the sand core can be detected and delivers additional information about the position orientation and distance.

4 CONCLUSION

In this research paper we have shown that optical sensors may well be used for data acquisition in the rough environments of foundries. Especially for middle sized foundries with automation levels from low to medium this approach is very promising. We have developed a complete object marking and recognition system for cast parts, including a self developed code, an autonomous mechanical marking element for molds and a procedure to recognize the marked cast parts by image analysis. With the planned improvements described above we expect to achieve acceptable failure rates. Furthermore we have investigated in sand core identification by image analysis. In that process we are not as close to an industrial application like in the case of cast parts. The main problem in this case is, that the recognition methods which work well are not rotation invariant. We plan to improve this method by adding notches to the cores, which allows the recognition procedure to identify the orientation in a first step.

Our next steps are further improvements for the processes described in this paper, especially regarding the robustness of our algorithms. Furthermore, there are more process parameters to be acquired, e.g. analysis of cast spurts and flask layout or damage recognition for sandcores. The initial analysis of our colleagues of mechanical engineering has shown, that the first two important acquired data sets described in this paper will already help to reduce failure rate in the examined foundries extremely. It is important to mention, that only a few defect cast parts may cause very high impact to total cost and, of course, to nature, because especially in medium sized foundries cast parts tend to be quite large, up to ten or twelve tons.

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