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Mobile Web App for the Digitization and Annotation of Manual Visual Inspection Tasks

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Abstract

Data acquisition and storage form the basis for information-driven decision-making processes and therefore play a central role in transparent production and quality assurance. Due to the complexity and variety of products, quality inspections are not necessarily automated and require expert knowledge of inspectors when performed manually. However, there is a lack of tools for digital data acquisition - especially for manual visual inspections. For such human-centered visual inspections, this paper presents a solution to support the inspector by a mobile web app, whose core contains an annotation function with defect classes and descriptions for process documentation.

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1. Introduction

Visual inspections continue to play a critical role in quality control in manufacturing of the 21st century. Along the value chain, the goal is to ensure that a product is defect-free prior to its installation in the subsequent stage of assembly or final delivery to the customer [1, 2]. The detection of defects not only allows their elimination but also the tracing of their root causes, taking necessary actions to mitigate them and preventing the further manufacturing of faulty components [3].

The common approach to automate visual inspections involves implementing image processing techniques, where camera-based systems combined with Artificial Intelligence are employed to detect damages [4]. Especially in small batch manufacturing, in which complex products with many variants can be present, such conventional concepts of industrial automation can be considered impractical due to their high implementation costs, time-consuming programming requirements, inflexibility, and the absence of digitized labeled data [5]. Thus, it is crucial to develop a solution that can assist human inspectors to establish a fundamental database, to take advantages of big data analytics, better connectivity, and the preparation for integration of automated solutions within this industry. The aim of this approach is to empower the worker to utilize a fully digital tool chain while utilizing their existing knowledge.

Therefore, this paper presents a mobile web application that supports the inspector in identifying, describing, and assessing any defects of a product by annotating a picture taken by a tablet device. For this purpose, we will clarify the importance of visual inspections in industry and present current work on annotation tools. Based on this, the next section serves to derive requirements and functionalities for the application. Subsequently, we will demonstrate the app's prototype and verify its usability within a user study. The app is intended to replace the manual written documentation and create a structured database that can be used for extended data analysis.

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2. Essentials & Related Work

2.1. Visual Inspection

Visual inspection is the non-destructive inspection method that is most commonly applied due to its speed and relatively low cost, as it relies on the raw human senses [6]. The resulting findings can be utilized for additional data analysis to determine the root causes of the detected errors, thereby improving processes. Visual inspection is typically the first approach for locating suspected defect areas [7] and is used both in manufacturing and MRO (Maintenance, Repair and Overhaul). In fact, more than 80% of inspections conducted on large transport category aircraft rely on visual testing [6]. Considering the case of aircrafts, [8] shows that currently most visual inspections are performed by human operators because of their expertise to make decisions, respond to unforeseen circumstances, and use of their senses. There are several steps involved for an inspection, including thorough preparation, analysis of inspection documents, working through a checklist or inspection plan, and recording the quality of the inspected object. In many cases this documentation is still analog and therefore error prone [9].

Thus, various automated solutions to eliminate errors in manual written documentation - hence enhancing the quality of visual inspections - have already been presented [10, 11] . One approach to accomplish an improve in quality is to transfer several human tasks of the process to machines to automate them. For example searching for a defect and deciding which defect is present can be automated by the use of high-resolution camera systems in combination with state-of-the-art deep learning algorithms [12]. Nonetheless, deep learning techniques are characterized by their high demand for input data: acquiring and annotating data requires significant effort and time. While many well-curated and meticulously annotated public datasets for general object detection exist, whereas industrial inspection scenarios are unique and require the collection and annotation of specific datasets for various targeted applications [13]. A trained inspector is necessary to ensure the consistent labelling of the required data [14].

However, this task is time-consuming and therefore not feasible in the daily work of these required human inspectors. Here it is crucial to support the inspector with an easy-to-use, cost-effective tool that helps to generate reusable digital data that can be used for future applications, especially in areas of manufacturing where digital data is not yet available or acquired. The potential benefits of such digital tools to support employees in their daily work will be clarified with several examples in the next subsection.

2.2. Mobile Annotation Tools

Mobile annotation tools have already been incorporated in various areas of industries to accelerate the access to crucial information, digitize paper-based records, and optimize the use of newly generated data. An augmented reality (AR) tool was presented by [15] to aid workers in visually inspecting and annotating defects in prefabricated houses. The tool runs on a tablet, uses a virtual model of the prefabricated module and the camera to enable visual inspections with geolocated annotations. Information generated in the process is stored within a database and can also be edited by other inspectors simultaneously or at different times. Another AR-based solution [16] is utilized in the manufacturing environment for annotating stationary objects with application data. This data can include maintenance records, service tickets, usage logs, but also sensor data that is send by smart machines with networking capability. Their system leverages a digital layer, in which all annotations are displayed, superimposed over the physical workspace. This enables a quicker access to crucial data (e.g., sensor data, maintenance order) which aids other employees in carrying out necessary work on these stationary objects.

For healthcare, a mobile annotation tool has been developed by [17] to supplement endoscopic videos of surgeries with text content, freehand drawings, and angle measurements on a tablet. In the daily work routine of healthcare professionals, tablets are already well integrated, helping to communicate, plan and review medical data between each other and with the patients. The annotation of the recorded videos allows patients to have an improved understanding during debriefings and can be further used for educational purposes.

In summary, the integration of mobile annotation tools has led to improved and simplified communication within companies as well as with customers, allowing a better understanding of previous performed actions and documentation and creating more valuable data without additional work for the employee. However, none of these solutions are designed for the domain of visual inspection of industrial goods, which means that a direct transfer of the presented solutions is not possible. Due to the special characteristics of inspection processes, these principles need to be adapted to the field of application. Therefore, requirements for this are derived and a first implementation is presented in the following sections.

3. Requirement Analysis

For the derivation of functional requirements and features of an annotation tool for visual inspections, a process analysis in cooperation with an aircraft cabin manufacturer was conducted. To ensure that the resulting tool is also transferable to other visual inspection processes, special attention is paid to the easy adaptability of specific informational and functional entities. Non-functional requirements are not in the focus of this work, yet general guidelines applied are briefly highlighted.

3.1. Process Description

In the manufacturing of aircraft cabin interiors, visual inspections are an essential part of the quality control processes between and at the end of assembly steps. In the current process no additional supportive devices or tools are used. Due to the complexity and the large number of variants that exist because of the individual requests of the different airlines, intelligent automation solutions are difficult to implement economically. The inspection processes therefore rely heavily on the employee's knowledge and experience. In addition, visual inspections are usually documented on paper, and any damage detected is drawn on printed component drawings. Minor, reversible damage may also be repaired directly without documentation. In this context, there are no defined defect classes, which makes it difficult to cluster individual defects into categories for later root cause analyses. Digitization of the inspection results occurs in a later process step and is associated with additional effort. This can increase the risk of media discontinuities between shop floor and design department, leading to potential errors being transferred to new projects or products. Based on this process and the deficits identified, requirements for the annotation tool were derived together with the aircraft cabin manufacturer, which are explained in more detail in the following subsection.

3.2. Functional Requirements

In this section, the essential functional requirements are explained in more detail. For better clarity, these are first shown as a list and then explained in more detail:

- Image Capturing (Requirement 1)
- Defect Localization (Requirement 2)
- Adaptable Defect Classification (Requirement 3)
- Defect Details & Description (Requirement 4)

The main goal of the annotation tool should be to assist the human worker in gathering information while conducting the inspection task. Since the decision about the presence of a defect is made by the employee based on visual features on a component surface, it is important to collect this information. Therefore, one main requirement for a support tool is the possibility to capture images to retain this information (Req. 1). Based on this, the existing picture must be further enriched with information. One of these pieces of information is the position of the defect(s) on the image; this localization of the individual defects with the help of suitable segmentation shapes constitutes a further requirement (Req. 2).

Due to the current lack of defined defect classes, the data basis for further analyses is missing. This is to be remedied with a possibility to create defect classes with the annotation tool. Each domain with the respective product range has typical occurring defects in its manufacturing that should be detected within the visual inspection. Since not every defect occurs in every product, the definition of generally valid defect classes is difficult. Therefore, the app must be adaptable to every situation so that it can be used for every needed visual inspection (Req. 3).

However, only the assignment to a class is not sufficient for the description of a defect. For this reason, the previous paper-based documentation is to be transferred to the annotation tool. This will eliminate the previous media discontinuity and shorten the overall process time. For further description of the defect, in addition to textual information, options for enriching an individual defect with detailed photos are to be provided to potentially increase traceability and information quality (Req. 4). The above-described requirements form the main foundation for the development of the actual tool with its functionalities.

3.3. Non-Functional Requirements

Besides the pure functional requirements, non-functional aspects cannot be neglected for the successful development of the tool. However, an explanation of all requirements of this kind will be omitted and two main points will be examined in the following.

One of these requirements is the easy integration of the application into existing processes as well as manufacturing and software environments. It should be possible to easily scale the application to multiple workstations, using either low-cost hardware or existing hardware to run the software anyway. In addition, the integration of the data into the existing software environment should be taken into account by using common data transmission protocols (Req. 5).

Another core aspect is the human-machine interaction and the efficient design of this interface. When developing and designing the user interface, it is important to create an application that can be easily used by any user at any age. The DIN EN ISO 9241-12 [18] provides a basis for the visualization of information so that tasks can be performed effectively, efficiently, and satisfactorily. This norm specifies the following seven characteristics in the design of visual information: Clarity, distinctiveness, compactness, consistency, recognizability, readability and comprehensibility. These characteristics influential in the design of the application and together represent the final requirement (Req. 6).

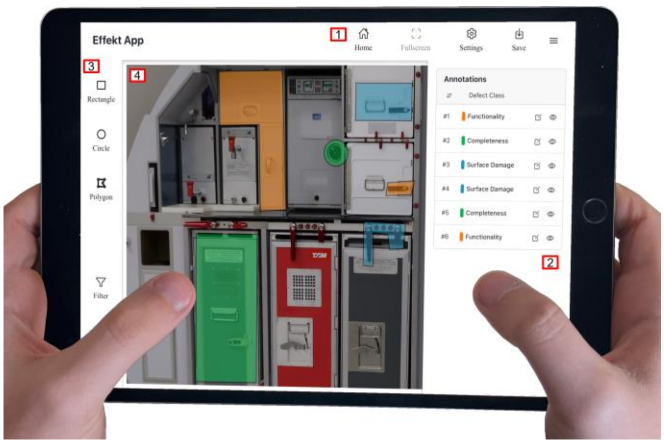

Fig. 1. Tablet running the application with an annotated picture of a cabin monument [19]. A defect class is shown with the specific color of the shape. The partitioning of the user interface with [1] the navigation bar, [2] the side bar with annotation history, [3] the tool bar and [4] the editor window is shown here.

4. Implementation of the Mobile Annotation Tool

In this section, the structure of the developed web app with all its functionalities will be presented and explained. To meet the need for a cost-effective and simple integration into existing processes (Req. 5), it was decided to develop the app as a web-based application, programmed in JavaScript, HTML and CSS. This brings the advantage that the app can run on any device with an internet browser, regardless of whether it is a desktop, tablet, or smartphone. However, for the given use case, the web app was designed to be used on a tablet. Tablets have been successfully utilized as a mobile device in manufacturing and are the only hardware required, making them inexpensive to purchase.

4.1. The User Interface

An uncluttered and straightforward user interface is the key for an easy-to-use application. Based on the provided information in Req. 6, it was determined to subdivide the interface in four main parts. Located on the upper side (Fig. 1, 1) is a navigation bar, in which important functions for handling the annotation are arranged, such as the settings, save and home button, and the possibility to open a side bar (Fig. 1, 2), in which all performed annotations are displayed in a list. The toolbar (Fig. 1, 3) with the annotation functions is positioned on the left side where the user can decide with which geometric shape (rectangle, circle, or polygon) the errors should be marked. The editor window (Fig. 1, 4), which occupies the largest area of the interface, is used to display the image and the individual annotations. It is possible to use the app in landscape or portrait mode, depending on the format of the image which should be annotated.

4.2. The Annotation Process

To be able to capture an image (Req. 1) the tablet camera is utilized to take a photo of the part which should be inspected. After the picture is displayed in the editor window, the detected defects can be annotated using the functions within the toolbar. Depending on the shape of the defect, the appropriate function is selected to outline and mark the damage with natural touch motions on the tablet (Req. 2). Although the rectangle and circle functions are appropriate for marking simple defects, the polygon function can also be utilized to accurately mark geometrically complex defects. After the initial shape creation, it is still possibly to move and scale the shape to fit the damage outlines.

Once the defect is marked, a pop-up window opens for classifying and describing the error (Req. 4). For this purpose, a suitable defect class and the corresponding individual defects must be selected from a previously created catalog. A free text can be inserted to describe the error in more detail, and, in addition, the severity of the error can be evaluated, to derive subsequent processes like a needed repair or a replacement of individual parts. Finally, additional detail photos can be attached to add different perspectives or close-ups. This process is visualized within a flow chart in Fig. 2.

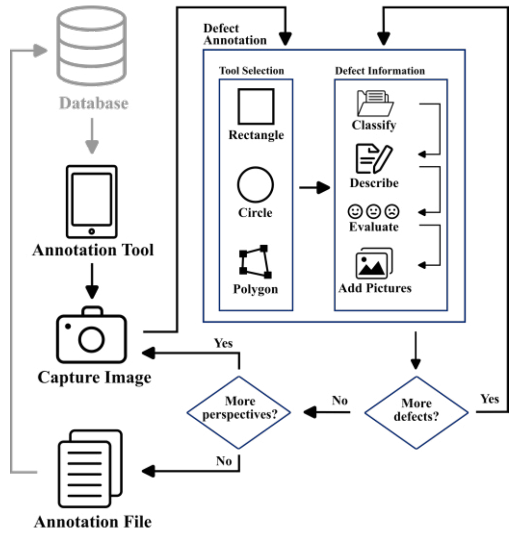

Fig. 2. The procedure of an annotation process using the application for visual inspections.

This simplifies the comprehensibility of the performed visual inspection in later processes or when involving additional people.

Once the annotation is confirmed, the defect is now visually marked on the image and colored, depending on the selected defect class. In this way, all defects from the same class can be clearly identified on the image, and it is also possible to apply a filter to display only the desired defect classes. Each entered annotation can be edited or completely deleted in the further process. When all defects are identified and classified, the visual inspection is completed, and the annotated image will be exported with all further maintained information. The annotated images are available as JPEGs and the defect information is exported as a JSON file, as exemplary shown in Fig. 3.

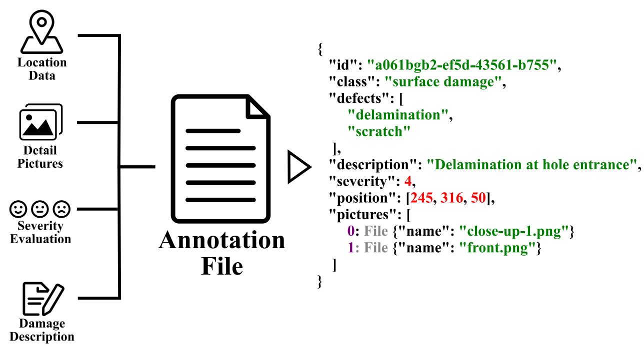

Fig. 3. Example of an annotation file formatted in JSON containing the location and description of the damage, as well as additional detail pictures.

4.3. Role-Based Functions

In addition to an "inspector-role", which is designed for the worker performing the inspection, there is also an "admin-role". While the inspector can use any functions needed to successfully perform a visual inspection, the admin can customize the app to meet the needs of specific inspection areas (Req. 3). Firstly, the admin can adapt the subsequent processes to the company's internal regulations, since the evaluation of occurring damages differs across parts and assemblies. Furthermore, this role can customize the damage catalog directly in the app or by importing a JSON file containing the required defect classes and the associated individual defects. This allows the app to be used in a wide variety of scenarios.

5. User Study & Usability Validation

To validate the usability of the developed annotation tool, a user study was conducted and evaluated, which will be presented in this section. Ten volunteers participated in this study, in which a visual inspection of a cabin monument was recreated in a laboratory environment. The functionalities of both the inspector role and the admin role were examined. For the first-mentioned role, predefined defects on the test component needed to be annotated using the app, and within the admin role, the study participants were asked to add new defect classes.

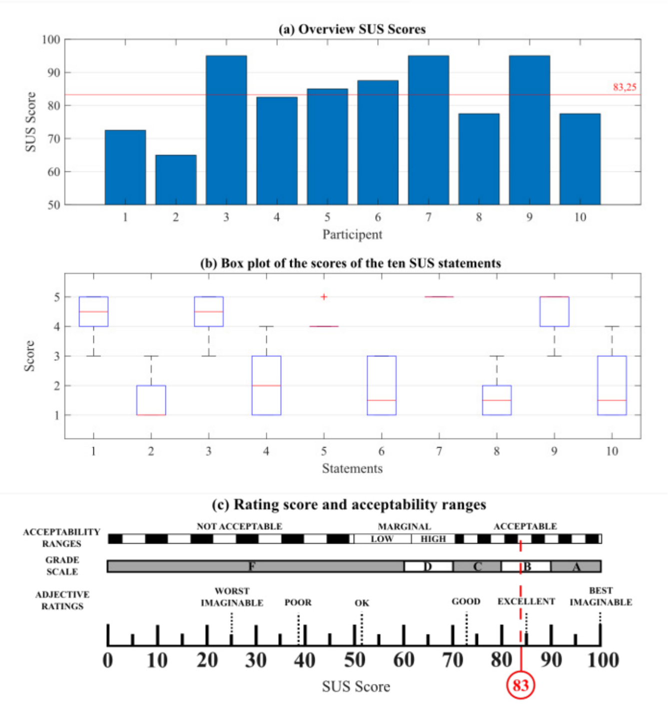

Fig. 4. (a) Overview of all archived SUS scores in the user study; (b) Box plot of the archived SUS scores of the ten SUS statements; (c) SUS rating score and acceptability ranges with archived overall SUS score (red).

The System Usability Scale (SUS) test, created by John Brooke, was used to validate and measure the usability of this app [20]. The SUS was selected because it is based on an easy-to-use scale providing reliable and robust results even with a small sample size. The questionnaire comprises ten statements, each offering five response options ranging from "strongly agree" (5 points) to "strongly disagree" (1 point). The scoring system range goes from 0 to 100, which often leads to misinterpreting the SUS score as percentages. Therefore, the final score in a grading scale [21] as well as the individual scores and box plots of the specific questions are illustrated in Fig. 4.

The conducted study has resulted in an average SUS score of 83,25. This result can be classified between good and excellent and confirms an acceptable usability of this application. Additionally, participants were given the opportunity to highlight successful functions and name missing features that could improve the use of the app. The participants particularly emphasized that the association between the defect image and the description represents a significant added benefit, as well as the possibility of attaching additional images to particular defects. The selection of different shapes for marking the damage was noted as being dispensable and will be addressed in the next section.

6. Conclusion & Outlook

6.1. Summary

Visual inspections continue to play a major role in quality control in manufacturing and maintenance. The goal is to detect damages in time to secure the quality, but also to support root cause determination for optimizing and improving processes. Despite existing automated solutions, inspections are still frequently carried out by humans, especially in small batch production. This is partly due to the high number of variants and complexity, which makes automation economically unattractive, but also due to the lack of digital labeled data, which are necessary for implementing such systems. Therefore, this paper presented a mobile web-application that on the one hand supports the inspector during the visual inspection, but also creates valuable digital data without adding time-consuming tasks. Running on a tablet, that has been a proven and cost-effective mobile device used in manufacturing, the application enables the possibility of taking pictures of the part and locate, mark, and describe the detected damages directly. This digital capturing of defects provides additional value to paper-based documentation by enabling the connection of multiple information within a single recorded defect. Due to the easy adaptability of the application, it can be used effectively and efficiently for any visual inspection of a wide variety of parts and assemblies. Within a user study, the usability was tested and validated by using the developed app in a recreated visual inspection of a cabin monument. The study not only confirmed the acceptable usability with an SUS score of 83.25, but also showed further potentials of the app, which will be discussed in the next and last section.

6.2. Future work

One goal of further work should be to implement the application into already existing database systems (as indicated in Fig. 2) for quality assurance processes. To simplify this implementation, it was already considered in the requirement analysis to provide the generated data in formats that can be leveraged in higher-level systems. The next step will be to define clear interfaces so that not only sending data can be realized, but also to utilize provided data within the app. Such data could be, for example, inspection plans for a clear assignment of the visual inspection performed or the predefined defect catalogs for the part under inspection. Additionally, the generated data within the app could also be sent to connected systems through typical Internet of Things protocols such as MQTT (Message Queuing Telemetry Transport). Collected at a central storage location, the data could then be used for more in-depth analyses, allowing patterns to be identified or the root cause of a damage to be determined.

Another essential aspect of future work will be to locate the tablet and the component within the inspection area and track the movement of the tablet using the internal sensors to provide the ability to connect to the virtual model. This virtual model will contain the CAD model of the component allowing to identify and mark the defects directly within it by using the annotation tool on the tablet. This will provide the advantage of knowing which components in an assembly are affected by the detected damage and will improve the visualisation of the occurring defects on the part.

Within the study, it was noted that marking with predefined shapes does not offer any added value. To make the app more efficient in the future, it will be a better approach to eliminate the shape tools and work with freehand drawings so that errors can be marked even quicker.

The establishment of these features within the application in connection with a database system could enable a fast and easy way to digitalize visual inspection effectively and cost-effective in manufacturing.

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