Augmented Reality for Dies Alignment in Machine Setup

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Abstract
Forging is one of the material deformation processing techniques. While the operation cycle is short and efficient, the machine setup process is generally long and time consuming. One of the difficulties in operation is position alignment procedure of the equipment during the die changing process. Due to the size and shape complexity of the machine and equipment, the operators are not able to clearly see the important parts – e.g. guided pins, holes, and sub-plate which need to be moved to finely adjust the alignment. Augmented Reality (henceforth AR) is used to solve this problem by rendering virtual objects and guides associated to those parts over the real equipment. Thus, the operators can monitor the position of the parts during the alignment process through the virtual objects. This AR system is developed based on ARcore SDK together with Unity on the Android platform. The experiment was conducted in real factory environment.

Keywords: Machine Setup, Forging, Augmented Reality, Die changing

1. Introduction

1.1 Forging Processes and Machine Setup
Forging has emerged as powerful platforms for bulk material deformation processing and is also able to produce high-strength workpieces. Traditionally, a metal billet has been inserted between an upper and a lower dies which is pressed by a hydraulic press machine to form the workpieces according to the shape of the cavity [1, 2].

Machine setup is a process of preparing the system that includes a workstation, machine, and operator to complete the work. The machine setup for the forging process generally consists of several complicated steps. The main challenge faced by many researchers is the setup time, which is considered time-consuming. Thus, recent evidence suggests that the setup time should be reduced [3].
Shingo (1985) [4] developed a well-known machine setup improvement method, Single Minute Exchange of Dies (SMED). The setup activities are categorized into four groups. The “measurement” and “adjustment” may take up to 15% of a whole process of time. It has been demonstrated that using special tools can reduce the time and difficulties in individual operations.

Regrading the forging process in the factory used in this current study, the original setup process for dies changing between the two models (i.e. 80 mm. ball valve: MB80 and BV80, in ENOMOTO 700GFH hydraulic press machine) take approximately 90-120 minutes by the two operators. Vongbunyong et. al. (2019) [5] improved the setup process by developing a semi-automatic system. The setup time is reduced to around 25 minutes, which are reduced by 65%. In a study conducted by Vongbunyong et. al. (2019), it was shown that an additional AR tool developed could assist the operators in adjustment and measurement operations during the IED activities.

1.2 Augmented Reality (AR)

More recent attention has focused on the provision of AR which is combined between a real-world and a virtual-world. The computer graphical models are created and rendered on the top of the real-world image for showing desired contents. AR can be classified into two categories. The first group is called a marker-based AR. It is simple and has been widely used in most applications. The program can locate and track the objects and environment in reality. In this regards, the marker that is a part of an object in computer vision tracking e.g. 2D image, 3D object, and sound. Second, the markerless-based AR is also considered to be more complicated than the marker-based AR. Concerning development of the technique, It does not require markers to operate but it can calculate the position directly from the environment. The localization can be done from an environment around the object by using related information, which is acquired, from many sources, e.g. computer vision, GPS location, and accelerometer.

Early examples of research into AR technology include industrial applications of AR to develop an AR system for planning and installing pipes in large ship assemblies (Olbrich et al., 2011). AR created virtual images from the CAD model and render over the real world image. The user can plan the route, customize the shape of the pipe and check the accuracy of the position immediately before the actual building and installation. Oliver Wasenmuller et al. (2016) [11] developed an AR system for the inspection of manufacturing errors which are discrepancy between 3D models and the real objects. RGB-D Camera was used and resulted in less than 0.01 m error.

1.3 Summary of SDKs

Recent advances in developing information technology methods have facilitated the investigation of the software development kit (henceforth SDK). AR applications were carried out using SDK which is based on our existing platform, Android and Unity. Criteria for selecting the SDK were shown in Table 1 below.

| Factor       | Vuforia     | Wikitude    | ARcore     |
|--------------|-------------|-------------|------------|
| (1) License  | Free for developer | Free for academic license | Free API   |
| (2) Unity3d plugin | Yes       | Yes         | Yes        |
| (3) Supported platform | Android, IOS, Windows | Android, IOS | Android    |
| (4) 2D tracking | ★★★★★      | ★★★        | ★★         |
| (5) 3D tracking | ★★★        | ★★★        | -          |
| (6) SLAM tracking | ★★        | ★★★        | ★★★★★     |

(a) Vuforia [6] is the most popular SDK for new developers, especially for Marker-based AR. It can work on a variety of platforms. Simple AR programs can be created with minimal knowledge of
programming. Tracking of high-speed objects is possible but less accurate than ARcore. It works well with 3D object tracking. It offers many features e.g. extend tracking, instant tracking, etc.

(b) Wikitude [7] can work on a variety of platforms. Intermediate level of programming skills is required for developing moderate tasks. It is compatible with Unity, Cordova, Xamarin and Android studio. For high-speed 2D/3D SLAM tracking, the performance is very high in comparison to Vuforia. It offers special features that are unavailable in most SDKs, i.e. a 3D marker for large scale object.

(c) ARcore [8] as an SDK working on Google's platform for developing AR on Android devices. Both marker-based and markerless-based AR can be developed. It can learn from the environment so that the detection and measurement of objects can be done precisely. Extended tracking is more efficient in comparison to (a) and (b), in which the main problem is to keep track of the objects. The limitation of ARcore is the speed of the objects that need to be tracked. However, from the observation of this machine setup system, ARcore is capable. As a result, ARcore is the most suitable SDK for this research.

Regarding the related technique, simultaneous localization and mapping (SLAM) [9] is one of the important localization concepts used in robotics. SLAM consists of two primary functions: creating a map from the surrounding environment and finding a location of the device in the map relative to the position and gesture data from various sensors. Initially, SLAM is often used in machine vision with 3D sensors. It is then developed to use with 2D imaging, e.g. 2D phone camera. This concept is Monocular SLAM [9], which is a starting point of various AR systems on current mobile devices.

2. Problems overview

2.1. Related components in dies changing process

The machine setup, in this case, is to exchange the dies between two models, MB80 and BV80. For each model, the dies consist of 3 parts which are upper die, lower die, and insert. (a) The upper die is attached with the upper plate, which is mounted on the ram. (b) The lower die is mounted on the sub-plate, which is mounted on the base. On the sub-plate, there are 4 holes for the guideposts and 4 holes for the cushion posts, where all the posts are on the base (see Figure 1 a). These posts are to align the sub-plate and lower die. The detail operations are presented in [5].

![Figure 1. Components in the machine and dies set [5]](image)

2.2. Problem and solution

This research focuses on the operation that moves the sub-plate and the lower die into the machine where the alignment is crucial. The sub-plate and the lower die maximum size is 910 mm. x 1,921 mm. x 430 mm. and around 1,100 kg weights is very heavy for manual operation. These components are placed on the guide rails and manually slid into the machine on top of the cushion and guideposts.

As the alignment of the posts is essential, the problem arises when the operators need to see the components clearly for the best alignment. The discrepancy between the holes on the sub-plate and the posts on the machine needs to be observed while sliding the components. As can be seen in Figure 2,
this is impossible according to the workspace and parts of the machine that obstruct the view of the operators.

Thus, this work aims to implement an AR technology to help the operator as a role of a decision tool for localization of the components. Markerless-based AR is considered because of two main reasons (a) attaching a marker in the workspace is impractical due to the rugged condition of the shop floor. The surface of components is dirty and coated by lubricants so that the marker will be occluded. (b) Direct object recognition of the components is impractical and complicated due to the limited number of feature points. To rule out the possibility that Markerless-based AR and SLAM will occur, the algorithm can be used to memorize the position and orientation of the markers. It is also attached out of a workspace area to create the virtual model of the machine. Two AR concepts are adopted to resolve this problem.

Figure 2. (a) Alignment: posts and the sub-plate (b) Current observation (c) Concept 1 (d) Concept 2

2.2.1. Concept-1: using 2 AR markers to notify a discrepancy of 2 models
The two markers were chosen to show two virtual models in this concept. There is one at the sub-plate and one another at the machine so it allows the system to calculate the distance and orientation between the two markers. The user interface can inform the operator how to move the sub-plate to the right position directly, such as showing a direction arrow, showing the top view, showing distance numbers as shown in Figure 2 c.

A major problem with the experimental method is that the technical issues and usability is becoming problematic. For example, the process of overlaying of many virtual models can be confusing than being assisted the user. As a result, the appropriate content display management is considerably complicated. Besides, the accumulated error in SLAM affects the discrepancy calculation. Therefore, this problem is related to SLAM algorithm within the SDK, which cannot be modified at this stage.

2.2.2. Concept-2: using only 1 marker to generate the final position model of sub-plate
This concept is likely to assist the user and is similar to the previous concept. The difference is that only a marker is used to construct the virtual model of the sub-plate at the final position. Then, the user needs to move the sub-plate to that position. By attaching a marker to the machine, the virtual guidance posts can be elongated from the actual posts so that they are observable directly from above the sub-plate (see Figure 2 d). This guidance model would be tested to investigate the accumulated error and the practicality of the AR system. This can be further developed to implement the procedure in concept-1 in the future.

3. Methodology
In this research, concept-2 is selected to develop the AR system for the die alignment process. Also, the purpose of the study is to test the position error of monocular SLAM technology whether it has enough level of accuracy and precision to be used in the high precision industry.

3AR system design
As shown in Figure 3a, an Android mobile device was used to communicate between the operator and the AR system. The AR system consists of a marker attached on the hydraulic press machine for recalling the virtual model of the machine and rendering the operator.
The position and the orientation of the virtual model are calculated by SLAM’s map, which obtains from an environment scanned with a device camera. During the process, the SLAM’s map will find many reference planes with respect to the feature point clusters. The default plane should be manually selected as the main reference plane. Next, the marker is scanned to obtain the actual machine location and recall the virtual model. After that, a little distance error between the virtual model and the real object may be presented. Manually offsetting is required for the first time. After the virtual model has been rendered, the virtual guide posts can be seen by the operator. These posts will be the target position that the sub-plate will be removed.

The AR program is run according to the flowchart presented in Figure 3b. The working of this program can be divided into three parallel parts: (a) point cloud generator for finding feature point, (b) plane generator for finding feature point cluster that probably is the plane, and (c) the main process. In the main process, there are three operations involved: environment scanning, selecting the default plane, and marker scanning. These operations will be conducted as described above.

![Figure 3](image)

**Figure 3.** System overview (a) system diagram (b) program flowchart

### 3.2. System configuration and setup

AR core is used to develop the markerless-based AR with SLAM in this research due to its robustness, speed, stability, and accuracy, which are better than other reviewed SDKs (see Table 1). It runs on the Android platform with the Unity environment. Some limitations are found. One of these is that it cannot track a fast object and detect a 3D marker. However, they do not affect the requirements of this research.

The Android phone is connected to the computer via a USB cable. The development environment includes: (a) Unity 2017.4.15f1, (b) ARcore SDK for Unity 1.4.0 and (c) Android SDK 7.0 API Level 24. After the application has been built, it will deploy on the phone to be used in the experiment.

The development and preliminary experiment were conducted in the lab. Significant changes in the environment occurred when the experiment was conducted on the shop floor. The setup can be described in the following issues:

(a) Workspace refers to the area that the sub-plate can be moved, which is 950 mm. x 950 mm. This area is limited inaccessibility due to the structure of the machine so that the operator can see the sub-plate from only two sides.

(b) Marker is 100 mm. x 100 mm. attached on the hydraulic-press machine.
(c) Environment, the factory floor is metal and oily surface while the lab floor is a carpet with some pattern. This difference affects the performance for defining the reference plane. The patterned carpet has better features in term of the number, clarity, and consistency over time.

(d) Guideposts are mocked-up with two tubes for the lab version to prove the concept, while there are four guideposts on the actual machine. The diameters are 70 mm.

(e) Sub-plate is mocked-up with a cardboard box with guide holes for the lab version for easy moving. For the actual sub-plate, it is a heavy part which can be mobilized with assisted tools only.

4. Experiment

4.1. Objectives and Procedure

The purpose of the experiment was to verify if this AR system can achieve sufficient accuracy and precision of the position and orientation of the virtual model concerning the real objects. An acceptable tolerance between the guidepost and the guide hole is 7 mm. The system performance needs to satisfy this value.

The experiment was conducted in the lab and on the shop floor. The lab experiment was used to predict the maximum performance with minimal effects from the external environment. On the other hand, the shop floor experiment aimed to investigate the factors related to the actual working conditions that might affect the performance of the system. The experiment procedure is set out to:

1. Prepare the model and the guideposts (see Figure 4 a-b);
2. Start scanning the marker (see Figure 4 c);
3. Scan the area associated with the machine and select the default plane (see Figure 4 d-e);
4. Manually adjust the offset of the model to match the machine (see Figure 4 f); and,
5. Move the camera angle from the original position and observe the changes.

Figure 4. Experiment on shop floor
4.2. Results and Discussion

From the lab experiment, the experiment shows an error of the AR system. In an attempt to keep all factors to reach the highest performance, the average error is between 50-80 mm. The test last 10 times.

Concerning the shop floor experiment, the program was quite unreliable because the number of feature points to be detected is decreased in the actual working area. The current study found that it is due to the surface that is coated with oil stains and similar color.

Regarding the error of ARcore, the movement of the model is similar to the experiment in the lab environment. Within the 800 mm around the front side of the machine, the system has an error between 50–80 mm. The results of this study indicate that the maximum error occurred when observed from the side view. Returning to the first position of the offset adjustment, the virtual model moved slightly from the original location. A possible explanation for this might be that there is an appearance of the ARcore due to the discrepancy ARcore SLAM's world and Unity's world. This issue should be taken into account.

Due to the uncertainty of SLAM map, in every model reconstruction, the virtual guidance model cannot be rendered at the same position with respect to the fixed offset from the marker. Therefore, manually offsetting is allowed to ensure that the model position is coincident with the real object. In regard to the change of the camera angle, the errors are associated with the SLAM mapping and data management of ARcore. These relationships may partly be explained by manual offsetting is allowed for fine positioning of the virtual model in two dimensions. Whereas the z-axis (height direction) is attached to the reference plane obtained from the ARcore algorithm. There are, however, other possible explanations. This result may be explained by the fact that the plane simplification algorithm of ARcore alleviated the virtual plane in order to compensate the roughness of SLAM map. Also, the error is caused by uncertainty data management algorithm in relation to internal problem of ARcore and general RGB-camera. Future studies on the current topic are therefore recommended.

5. Conclusion

The present study was designed to determine the effect of AR technology to solve the problem of wasting time from aligning the die's subplate. The results of this investigation show that creating of a virtual image model of the final position of the subplate can be replaced by the operator i.e. moving the subplate to that position. During the development of this program, problems were found in the process of adjusting models offset, due to three main problems: human error, plane error, and ARcore error. The study contributes to our understanding of a system that can help adjust the alignment. This study appears to be the first study to use a system to eliminate the human error. The major limitation of this study is that the other errors cannot be resolved because of an internal problem caused by the SLAM algorithm of the ARcore SDK.

Further work needs to be done to establish whether other errors can be resolved and clearly identified. Further research should be undertaken to explore how error values occur from those problems. There is, therefore, a definite need for conducting an experiment to collect the error values that occur from those problems. These findings suggest using the test with simulated environments that control various factors in the condition than the program will be the most effective. Also, the result of the experiment showed that the maximum error value occurred was 50-80 mm, which is worse than the acceptable error value of 7 mm. SLAM algorithm must be improved to resolve this problem.

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