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# 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 generally long and results in time waste. One of the difficulties in operation is position alignment procedure of the equipment during the mold changing process. Due to the size and shape complexity of the machine and equipment, the operators are unable to clearly see the important parts – e.g. guided pins, holes, and sub-plate - which need to be delicately moved to adjust the alignment. Augmented Reality (AR) technology is used to solve this problem by rendering virtual objects and guides associated to those parts over the real equipment. As a result, the operators are able to monitor the position of those 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, Mold changing

## 1. Introduction

### *1.1 Forging Processes and Machine Setup*

Forging is a conventional yet important technique for bulk material deformation processing that is able to produce high-strength workpieces nowadays. A metal billet will be inserted between an upper and a lower dies and pressed by a hydraulic press machine in order to form the workpieces according to the shape of the cavity [1, 2].

*"Machine setup"* is a process for preparing the system, including of workstation, machine, and operator, in order to complete the work. The machine setup for the forging process generally consists of a number of complicated steps. The setup time can be considered waste since the workpieces cannot be produced during the setup process. Hence, the it should be optimized to reduce the setup time [3].

S. Shingo (1985) [4] studied and developed a well known machine setup improvement method, *Single Minute Exchange of Dies* (SMED). The setup activities can be categorized into 4 groups and the “measurement” and “adjustment” may take up to 15% of the time of the entire process. After work study is applied to optimize the process, using special tools will be considered to further reduce the time and difficulty on individual operations.

According to the forging process in the factory that we study, the original setup process for dies changing between 2 models (80 mm ball valve: MB80 and BV80, in ENOMOTO 700GFH hydraulic press machine) was 90 - 120 mins with 2 operators. Vongbunyong *et. al.* (2019) [5] improved the setup process by developing a semi-automatic system. The setup time is reduced to around 25 mins which is reduced by 65%. In this research, an additional Augmented Reality (AR) tool is developed in order to assist the operators in *adjustment* and *measurement* operations during the IED activities.

### *1.2 Augmented Reality (AR)*

AR is a technology that merge between the real world and the 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, *Marker-based AR* and *Markerless-based AR*. (a) *Marker-based A*R is a simple AR widely used in most applications. The program can locate and track the objects and environment in the real by using a “marker” which is an object for computer vision tracking, e.g. 2D image, 3D object, sound, etc. (b) *Markerless-based AR* is more complicated than the marker-based AR in term of development. This technique requires none of the markers to operate but 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, accelerometer and etc.

A number of industrial applications were developed with AR technology, for example M. Olbrich *et al.* (2011) [10] developed an AR system for planning and installing pipes in large ship assemblies. AR created virtual images from 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 0.01m error.

### *1.3 Summary of SDKs*

The development of AR applications is mostly performed by the software development kit (SDK). Based on our existing platform that is Android and Unity, three SDKs suits the requirements, Vuforia, Wikitude, and ARcore. The comparison is shown in Table 1.

(a) *Vuforia [6]* is the most popular SDK for new developers, especially for Marker-based AR. It is able to work on a variety of platforms. Simple AR programs can be created with minimal knowledge in programming. Tracking of high-speed objects is possible but less accurate than ARcore. It works well in 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 are required to perform simple to moderate tasks. It is compatible with Unity, Cordova, Xamarin and Android studio. For high-speed 2D and 3D objects tracking, the performance is very high in comparison to Vuforia in the SLAM tracking. It also provides some special features that is unavailable in most SDKs, e.g. a 3D marker for large scale object such as buildings, etc.

(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 Vuforia and Wikitude, in which the main problem is tracking lost. The limitation of ARcore is the speed of the objects to be tracked. However, from the observation of the machine setup system, none of the objects moves faster than the capability of ARcore. As a result, ARcore is the most suitable SDK for this research.

**Table 1.** Comparison between SDKs

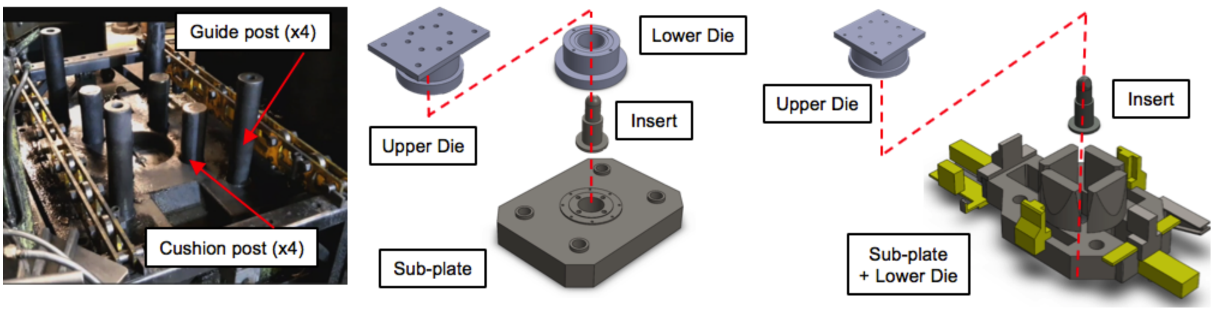
| Factor | Vuforia | Wikitude | ARcore |
|---|---|---|---|
| (1) License | Free for developer | Free for academic license | Free API |
| (2) Unity3d plugin | Yes | Yes | Yes |
| (3) Supported platform | Android, IOS, Windows | Android, IOS | Android |
| (4) 2D tracking | ★★★★★ | ★★★★ | ★★ |
| (5) 3D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

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 later developed to use with 2D imaging, e.g. 2D phone camera. This concept is Monocular SLAM [9], which is the 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 guide posts and 4 holes for the cushion posts, where all the posts are on the base (see Figure 1a). These posts are to align the sub-plate and lower die. The detail operations are presented in [5].




(a) Cushion and guide posts (b) BV80 (c) MB80

**Figure 1**. Components in the machine and dies set [5]

### *2.2. Problem and solution*

This research focuses on the moving operation that moves the sub-plate and the lower die into the machine where here the alignment of the components are 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 weight 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 guide posts.

As the alignment of the posts are essential, the problem arises when the operators need to see the components clearly for the best alignment. Discrepancy between the holes on the sub-plate and the posts on the machine needs to be observed while sliding the components. This is impossible according to the workspace and parts of the machine that obstruct the view of the operators (see Figure 2).

Thus, this work aims to implement an AR technology to help the operator as a role of 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 all components can be dirty and possibly coated with lubricants in which the marker will be occluded. (b) Direct object recognition of the components is impractical and complicated due to the limited number of feature points. By the advantage of Markerless-based AR and Simultaneous Localization and Mapping (SLAM) algorithm, the algorithm can be used to memorize the position and orientation of the markers, attached at out of workspace area, in order to create the virtual model of the machine. Two AR concepts are proposed to resolve this problem.

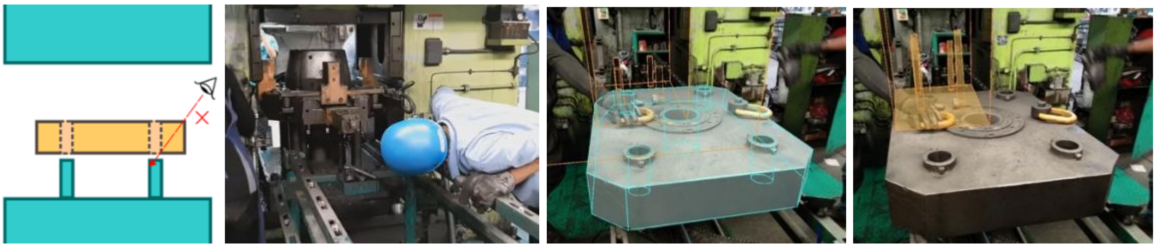


**Figure 2**. (a) Alignment: posts and the sub-plate (b) Current observation (c) Concept 1 (d) Concept 2

*2.2.1. Concept-1: using 2 AR markers to notify a discrepancy of 2 models*

This concept uses 2 markers to show 2 virtual models, one at the sub-plate and another at the machine. This approach allows the system to calculate the distance and orientation between 2 markers. The user interface can inform the operator how to moves the sub-plate to the corrected position directly, e.g. showing a direction arrow, showing the top view, showing distance numbers, etc. (see Figure 2c).

Although this concept is more intuitive and would facilitate to the user because the user can decide immediately, the technical issues and usability arise. Firstly, the overlay of many virtual models can become confusion than assisting the user. As a result, the appropriate content display management is complicated. Secondly, accumulated error in SLAM affects discrepancy calculation. 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 can help the user similar to the first concept. The difference is that only 1 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 2d). This guidance model would be tested the accumulated error whether the AR system can be used practically. 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 die alignment process. In addition, the purpose is to test the position error of monocular SLAM technology whether it has enough level of accuracy and precision to be used in high precision industry.

*3.1. AR system design*

An Android mobile device is used to communicate between the operator and the AR system (see system overview in Figure 3a). The AR system uses a marker attached on the hydraulic press machine to recall the virtual model of the machine and render for the operator.

The position and the orientation of the virtual model is calculated by SLAM's map, which obtains from a *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 a main reference plane. Next the *marker is scanned* to obtain the actual machine location and recall the virtual model. After that, 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 moved to.

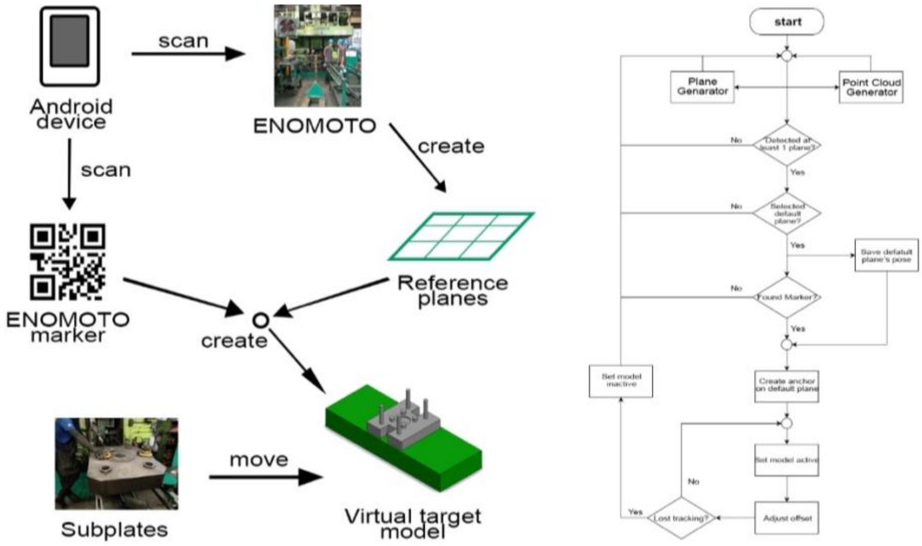



**Figure 3**. System overview (a) system diagram (b) program flowchart

The AR program is run according to the flowchart presented in Figure 3b. The working of this program divides into 3 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) *Main process*. In the Main process, 3 operations - Environment scanning, Selecting the Default plane, and Marker scanning – will be conducted as described above.

*3.2. System configuration and setup*

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

The Android phone is connected to the computer via a USB cable. The development environment include: (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 environment was 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 in accessibility 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) *Guide posts* are mocked-up with two tube for the lab version in order to prove the concept, while there are four guide post 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.

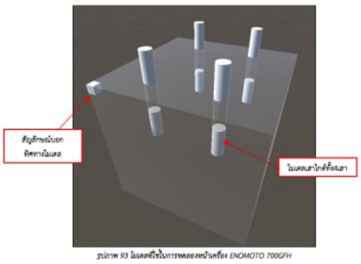
## 4. Experiment

### *4.1. Objectives and Procedure*

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

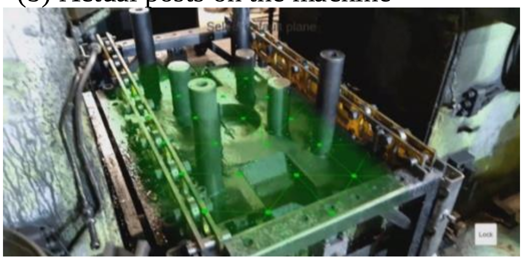
The experiment was conducted in the lab and on the shop floor. The lab experiment aims for finding out the maximum performance with minimal effects from external environment. On the other hand, the shop floor experiment aims for investigating the factors related to the actual working conditions that will affect the performance of the system. The experiment procedure is as follows:

(1) the model and the guide posts are prepared (see Figure 4a-b);
(2) start scanning the marker (see Figure 4c);
(3) scan the area associated with the machine and select the Default plane (see Figure 4d-e);
(4) manually adjust the offset of the model to match the machine (see Figure 4f); and,
(5) move the camera angle from the original position and observe the changes.





(a) Virtual model of extended posts (b) Actual posts on the machine



(c) Marker on the machine. (d) Scanning for the reference plane


(e) Render the virtual model (f) manually offset

**Figure 4**. Experiment on shop floor

### *4.2. Results and Discussion*

From the lab experiment, the experiment shows an error of the AR system. Attempt to keep all factor to reach the highest performance, the average error is between 50-80 mm. Test for 10 times.

For the shop floor experiment, the program was quite unreliable because the number of the feature points to be detected is decreased in the actual working area. This 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 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. This was occurred because of the ARcore error due to the discrepancy ARcore SLAM's world and Unity's world that cannot find exact causes.

## 5. Conclusions

This research applied AR technology to solve the problem of wasting time from aligning the die's subplate, by creating a virtual image model of the final position that the subplate should be placed in order for the operator to move 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. This research proposed a system that help adjusting the alignment to eliminate the Human error. But the other error cannot be resolved because it is an internal problem caused by the SLAM algorithm of the ARcore SDK, which cannot be studied.

Even though it is unable to resolve and clearly identify the cause of the problem, this research has conducted an experiment to collect the error values that occur from those problems. By testing with simulated environments that control various factors in the condition that the program will be most effective. The result of the experiment showed that the maximum error value that occurred was 50-80 mm which is worse than the acceptable error value of 7 mm. Knowing that the ARcore problem caused the program unable to use in actually works with the die changing process of the company.

## 6. References


[1] Groover, M.P., *Bulk deformation processes in metal working*, in *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems*. 2010, John Wiley & Sons. p. 405 - 420.

[2] Vongbunyong, S., P. Archeewawanich, P. Akaratham, C. Martchan, and K. Thamrongaphichartkul, *Automatic Handling for Valves Trimming System.* IOP Conference Series: Materials Science and Engineering, 2019. **501**: p. 012046.

[3] Andrade, F.d. *Machine Set Up Definition*. [cited 2019; Available from: https://www.academia.edu/10073499/Machine_Set_Up_Definition]

[4] Shingo, S., *A Revolution in Manufacturing: The SMED System*. 1st ed. 1985: Productivity Press.

[5] Vongbunyong, S., W. A., N. Suwanarawat, S. Phansaeng, and T. Tothong. *Semi-Automatic system for setup process of forging machine*. in *The 10th TSME International Conference on Mechanical Engineering*. 2019. Pattaya, Thailand.

[6] Vuforia developer, *Getting Started with Vuforia Engine in Unity*. [cited 2019; Available from : https://library.vuforia.com/articles/Training/getting-started-with-vuforia-in-unity.html]

[7] Wikitude developer, *Image Recognition*. [cited 2019; Available from: https://www.wikitude.com/external/doc/documentation/latest/unity/imagerecognitionnative.html#introduction]

[8] Googles Developers, *Fundamental Concepts*. [cited 2019 Available from: https:// developers. google.com/ar/discover/concepts]

[9] Imperial College London., *Mono SLAM*. [cited 2019 Available from: https://www.doc.ic .ac.uk/~ab9515/monoslam.html]

[10] M. Olbrich, H. Wuest, P. Riess and U. Bockholt, 2011, *Augmented Reality Pipe Layout Planning in the Shipbuilding Industry*. Fraunhofer Institute for Computer Graphics Research, Germany

[11] O. Wasenmuller, M. Meyer and D. Stricker, 2016, *Augmented Reality 3D Discrepancy Check in Industrial Applications*, German Research Center for Artificial Intelligence, Germany