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# An algorithm of marking line correction for robot-based layout automation of building structures

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**Abstract:** Robot-based layout automation has been recently promoted for the purpose of improving productivity and quality. Marking robots have various functional demands to secure marking precision and environmental adaptability. In particular, in order to automate marking work of building structure, correction of the marking line through position recognition of rebars placed is required. Because the rebars must maintain a constant cover thickness from the formwork surface, if the rebars are out of planned position, the rebar or marking line need to be corrected to secure the cover thickness. Thus, the marking robot for structural work needs to have the function for determining the position correction of the rebar or the marking line. In order to judge the correction of marking line, it is required to measure the distance between the planned marking line and the rebar placed. Therefore, this study proposes an algorithm that can measure the distance between the planned line and the rebar, and correct marking line for the automatic operation of the marking robot. The results of this study will be utilized as a core function for unmanned operation of the marking robot and contribute to securing precise marking by reflecting construction errors.

**Key words:** marking line correction, rebar position, marking robot, layout automation, building structure

## 1. INTRODUCTION

A robot-based automated marking system has been under development in recent years to increase productivity and marking accuracy [1]. Marking robots have different usages, depending on the working environments, and various roles according to their purposes. Specifically, a marking robot used for framework construction must secure accurate information according to onsite situations [2]. In order to secure the exact shape and position of the structure, the accuracy of the marking work is very important, which also affects the covering thickness of the rebars [3]. Accordingly, marking robots used in framework construction are required to have various functions to achieve the required accuracy.

Frame construction is a wet construction, so it is difficult to immediately check construction errors during pouring. Rebars are prone to deviate from the its planed position during pouring due to the pouring pressure or workers. In addition, since there is no marking line for the deviated reinforcing bar, it is difficult to confirm the position, so it is fixed as it is. In that case, it is necessary to move the rebar within the permissible range, or correct the markings to secure the covering depth. Such corrections are intuitively decided onsite by marking supervisors, and relevant corrections are applied to rebars or markings.

The function to determine a rebar error is necessary for automated marking robot operations. If a marking robot does not compensate for a rebar error and mark according to the original marking plan, it is difficult to assess the adequacy of the covering depth for rebars. In that case, an additional inspection process and corrected markings are required. To ensure that a marking robot operates without a supervisor, the robot needs to be equipped with a function that will allow it to assess whether a marking or rebar position needs corrections by measuring the covering depth.

Therefore, this study proposes an automated marking correction algorithm for a marking robot to compensate for rebar errors and correct markings according to the covering depth. This study first investigates conventional methods of marking corrections based on which the acceptable standards for corrections are established. A robot algorithm is then proposed to ensure that the measurement process is conducted followed by the evaluation of the marking corrections. The findings of this study will contribute to the improvement of the marking quality and unmanned operation of marking robots.

## 2. LITERATURE REVIEW

### 2.1. Previous studies

Previous rebar recognition and measuring technologies mostly focused on reinforced concrete construction and automated inspection processes. Evelyn et al. [4] conducted a study which focused on the inspection of rebar corrosion by measuring the rebar radii embedded in concrete using a guided wave. Kim et al. [5] conducted a study on the automation of rebar placement inspection before concrete casting using a LiDAR sensor. Jin et al. [6] conducted research on binding-point recognition for automated rebar binding robots based on the use of an RGB-D camera. Yuan [7] conducted a study on rebar inspection automation based on the use of an RGB-D camera to measure the spacings of slab rebars. Most of the previously published studies focused on the recognition or measurements of rebars with a laser or camera, and provided the measurement results to supervisors. Instead, this study concentrates on marking corrections based on rebar errors for automated operation of marking robots.

### 2.2. Marking correction standards

Framework corrections are performed when the framework is out of position, or when the covering depth has not been secured owing to rebars. In general, an exterior wall is corrected by adjusting the slope of a wall form; in the case of an interior wall, the position is adjusted by drawing the corrected markings. Given that the corrected markings alter the covering depth of rebars, corrections should be made after securing the covering depth. Marking correction standards are established such that breakaway rebars are bent and positioned within the covering depth range, while connecting rebars are constructed after drilling. Alternatively, the wall structure thickness is increased the rebars are outside the range. In the latter case, corrected marking lines are drawn. The margin of error in the covering depth of wall structure rebars is ±10 mm [8], and the allowable error for wall thickness is within 3% [9]. Accordingly, it is possible to correct the markings without moving rebars within 3% of the wall thickness if they are outside the margin of error of the covering depth. The rebars can be bent or drilled for the construction using corrected rebars if they are outside the margin of error.

## 3. REBAR POSITION MEASUREMENT PROCESS

First, the measurement process of the covering depth of rebars is required to determine the need for marking correction. Originally, this process requires a marking supervisor to measure the covering depth before the work is started and revise the on-plan markings. However, the robot measuring the depth can perform measurements using more diverse methods. The following three alternative proposals have been drawn among several alternatives through consultation with experts from various areas.

**Table 1.** Alternatives for measuring rebar cover thickness

| Alternatives | Measurement Method | Measurement Range | Measurement Process | Rate of Accuracy | Process Time | Equipment |
|---|---|---|---|---|---|---|
| 1 | Premeasurement using three-dimensional (3D) scanner | All rebar measurements on the surface | Premeasurement | High | Long measuring time | 3D scanner |
| 2 | Real-time measurement using LiDAR | Rebar measurement per line | Real-time measurement | Low | Short measuring time | LiDAR |
| 3 | | Rebar measurement per ponit | Real-time measurement | High | Short measuring time | LiDAR |

The first alternative involves the scanning of the overall positions of rebars using a 3D scanner before the marking process. It ensures accuracy by using coordinates of point-cloud data from scanning, and enables the corrected plan to be used given that corrections are possible before the marking process. However, it is difficult to extract rebar coordinates from the point cloud data, and one to two hours of calculations result in a longer marking preparation.

The second alternative involves the attachment of a LiDAR to a robot to measure the covering depth of rebars continuously placed within the wall structure per line and simultaneously carry out the marking process. In this case, the on-plan and correction lines can be drawn together so that there is no need for a separate correction process after the marking process. However, the measurement accuracy is decreased if the length of the wall construction line is long, and this may require a longer process as position data for all rebars on the construction line need to be collected and calculated.

The third alternative is similar to the second, but instead involves a robot to measure a few rebar covering depths at the operating points rather than measure the entire length of the construction line. It is possible to perform real-time markings and measurements simultaneously by collecting only a small amount of data. However, additional marking corrections may be needed because the lines are drawn per point discontinuously.

The first alternative requires an excessive amount of preliminary work which involves measurements and calculations, thus leading to an additional process that may lead to an extended, total process time. This is directly against the goal of using automated robots to increase productivity. It is thus considered unsuitable for this study.

The difference between the second and third alternatives is based on whether the measurements of continuous rebars are based on the line being measured, or on whether the point of rebar is based on its position per section where the robot is operating. The second alternative allows a continuous correction line, but this requires the measurement of all rebars along the length of the entire construction line. This will cause the measurement accuracy to decrease as the rebar gets further away from the measurement starting point. In addition, determining the correction criteria of the rebar position on the line is ambiguous. There are no criteria on the number or ratio of rebars that are out of line among all the continuous rebars. Hence, determining whether a correction should be made is challenging. In support of the decision-making process, it is necessary for the marking process criteria and rebar error data to be provided to both rebar and formwork supervisors as part of the marking process. Therefore, the measurement process will adopt the third alternative in which the robots measure the rebar in front of their operation points, and determine the covering depths.

The proposed process is shown in Figure 1. First, the robot stops at the operation point and scans the rebar installed in the next point section with LiDAR. Next, to reduce calculations, only coordinate data are extracted from the rebar installation area in the scan area. Finally, the distance between rebar and the marking line is calculated to determine the marking correction in the next operation section.

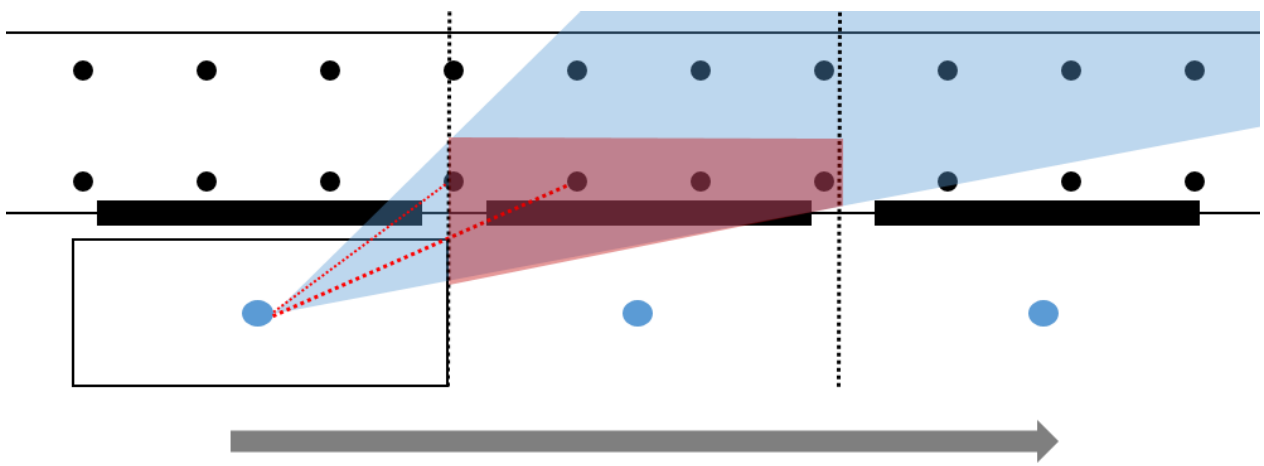

**Figure 1.** Rebar measurement process with LiDAR

## 4. MARKING CORRECTION ALGORITHM

It needs to be determined whether a correction marking process is needed based on numerical value after the measurement of the covering depth of rebars. The correction criteria were established based on the inside error of rebar position, the outside error of rebar position, covering depth tolerance, and wall construction thickness tolerance. This study proposed the marking correction algorithm, as shown in Figure 2.

① Measure the distance between rebar and marking ($T_r$: rebar-marking distance, $T_c$: structure covering depth, $T_w$: wall construction thickness)

② Determine if the rebar-marking distance compensated for the covering depth

· If $T_r \geq T_c$, assess whether the rebar is positioned inside of the original position and measure the rebar's inside error

· If $T_r \leq T_c$, assess whether the rebar is positioned outside of the original position and proceed to the next step

③ Assess whether the rebar position is within the range of covering depth tolerance

· If $T_r$ - $T_c \leq 10$ mm, the rebar is within a 10 mm covering depth tolerance and no correction is needed. Proceed to measure the outside error

· If $T_r$ - $T_c \geq 10$ mm, it is outside of tolerance range, and a marking or rebar correction are needed. Proceed to the next step

④ Determine the need for correction marking

· If $T_r + T_w \times 0.03 \leq Tc - 10$ mm, when wall construction thickness is added within the wall construction tolerance, the covering depth is within tolerance. Thus, it is possible to secure covering depth correction marking without rebar correction. Proceed with the correction marking process

· If $T_r + T_w \times 0.03 \geq Tc - 10$ mm, it is difficult to secure the required covering depth, regardless of whether wall construction thickness is added within tolerance, meaning rebar correction is needed. Proceed to the next step

⑤ Determine the need for on-plan marking

· If $T_r \leq 15$ mm, the rebar is positioned inside of marking point of the marking robot, and it is thus impossible to produce on-plan marking. Marking should not be performed

· If $T_r \geq 15$ mm, the rebar is positioned outside of marking point of the marking robot but is not possible to secure the covering depth. Therefore, rebar correction is needed. Proceed to the next step

⑥ Organizing corrected rebar data

· Corrected rebar data (position, distance, count) organization

⑦ Perform on-plan marking

· Perform on-plan marking or on-plan marking + correction marking

⑧ Document rebar correction report

· Write rebar correction report based on corrected rebar data

Case study was performed by setting the simple situation of this algorithm. The suitability of the algorithm results was analyzed when the distance between the rebar and the marking line was measured to be 25mm after casting in a frame construction where the wall thickness was 200mm and the rebar cover thickness was 40mm. In this situation, this algorithm derives the result of marking a corrected line that increases the thickness of the wall by 6mm. The distance between the rebar and the making line of 25mm is smaller than the 30mm allowable covering thickness of the rebar. Accordingly, the covering thickness of rebar must be secured by extending the wall, and the maximum allowable increase in wall width is 6mm.

In this case, if the wall width is increased by 5mm or more, the allowable covering thickness of 30mm is secured. As the result of the algorithm secures a wall line of 206mm and a covering thickness of 31mm, it can be considered that a suitable result was derived within the allowable range of the wall and covering thickness of the rebar.

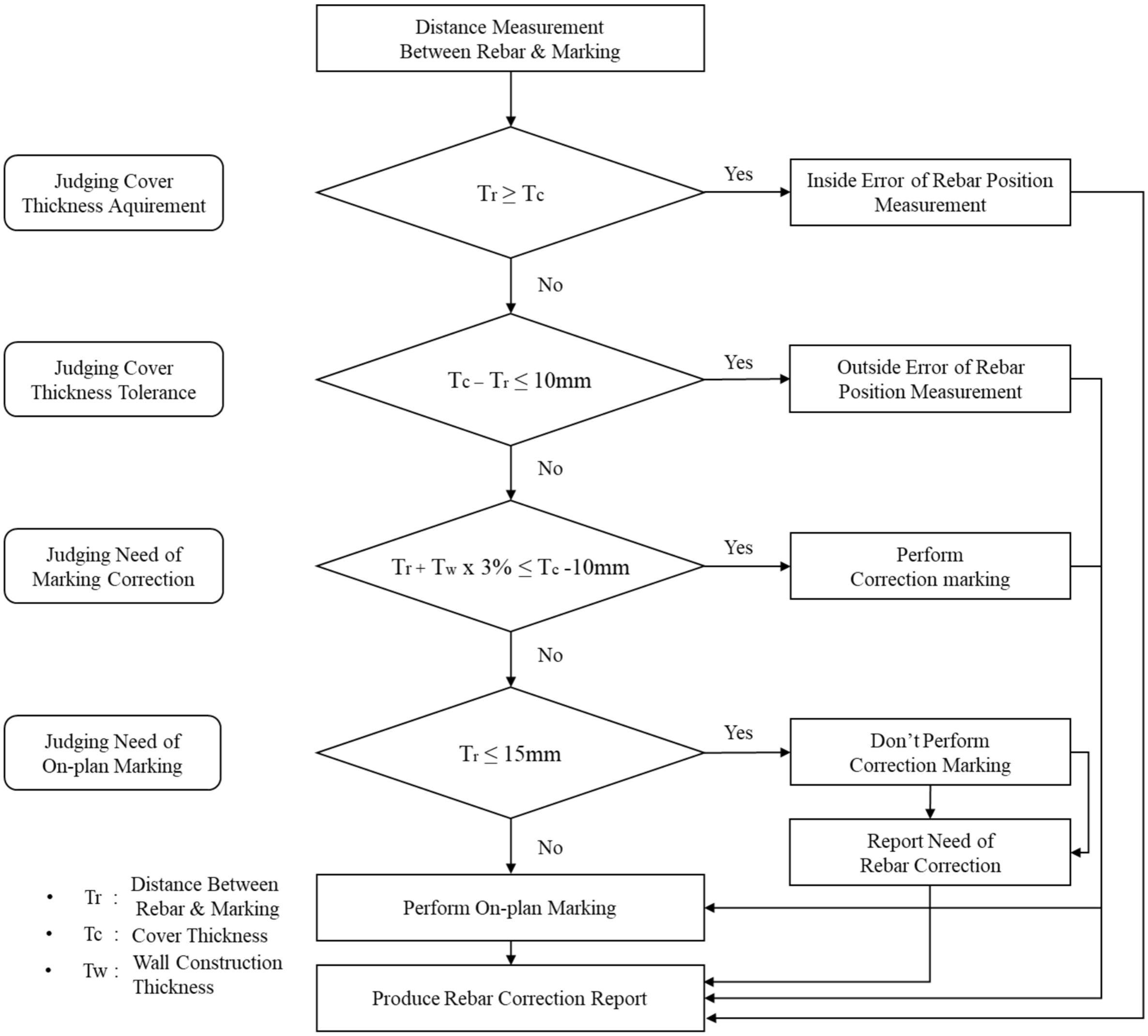


**Figure 2.** Marking correction judgement algorithm

## 5. CONCLUSION

This study proposed an algorithm for the automation of marking robots that can assess the correction marking that compensates for errors which occur during the construction process. First, the standards for measuring the error margin and tolerance were analyzed based on theoretical considerations. Subsequently, alternatives for the measurement standard judgment method were presented, and the measurement process was established by analyzing the advantages and disadvantages. Lastly, the correction algorithm that can assess the need for marking corrections based on existing standards, and determine the need of a marking process was proposed. The findings of this study can contribute to improved productivity through the automated operation of marking robots, and can achieve increased framework quality based on a marking process which compensates for framework errors.

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