Experimental evaluation of a robotic bolting device in steel beam assembly

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Abstract

This paper deals with a robotic system for the steel beam assembly task in building construction. Applying the robotic system on the steel beam assembly, we pursue such advantage as improving safety for workers and reducing construction period and cost. The robotic bolting device suggested in this paper has a gantry-type moving apparatus which includes a bolting end-effector. The bolting end-effector is designed especially for bolting mechanism using TS(Torque Shear) type bolt. In order to perform the bolting assembly tests, we made an experimental testbed which was similar to a real steel construction environment. Through the tests, we acquired feasible results for applying the robotic bolting device to real steel construction sites.

Keywords: Construction robot, bolting, steel beam assembly, robotic bolting device.

1. Introduction

In recent years, various studies have been attempted to employ robotic technologies to construction field. As an example, in Korea, a research on the development of the Construction Automation System of High-rising Building was initiated[1,2]. This system is based on CF(Construction Factory) technology[3,4]. CF is a factory-like structure in which several construction robots are equipped to automate construction works. This project consists of four research categories like follows: (1) Construction automation system planning and integration for robotic crane based high-rise building structure, (2) Climbing hydraulic robot and CF structure technology, (3) Robotic crane based construction material installation technology, and (4) RFID(Radio Frequency IDentification) and multi-DOF CAD based intelligent construction material supply system. Figure 1 shows a 1/20 size model of the construction automation system.

This paper focuses on "(3) Robotic crane based construction material installation technology". In order to perform the task (3), an automation system for robotic beam assembly was suggested[5]. In this study, the robotic bolting device for beam assembly was briefly reviewed and extensive experiments were performed to obtain bolting criterion to assure successful bolting tasks. With the results of the experiments, an angular criterion and a force criterion between the beam and the robotic bolting device were attained. They can be used for developing and improving the robotic assembly system.

2. Robotic bolting device

A robotic system used for construction automation is developed for bolt assembly automation[5]. In this study, we introduce a robotic bolting device that consists of a robotic manipulator and a bolting end-effector to assemble construction materials. For the robotic bolting device, a bolting mechanism using TS type bolt is employed, by which the bolting procedure can be fairly simplified.

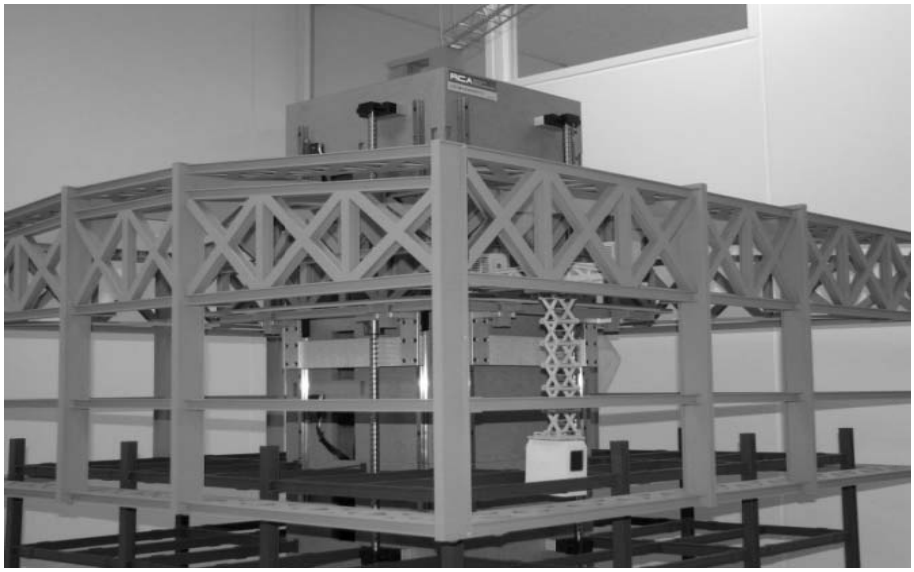


Figure 1. 1/20 size model of Construction Automation System of High-rise Building.

2.1 *TS type bolt*

Figure 2 shows a sample of TS type bolt which has a pintail and a breakneck at the end of the bolt. In a general bolting task, a worker should hold a hexagonal bolt head and rotate a nut against the bolt with a wrench. To use general bolts in the robotic bolting system, an additional device or more complex robotic systems are required. But by using TS type bolts in the robotic system, this problem is solved and lots of advantages are given to the robotic system. Since a bolting end-effector grabs both the bolt pintail and the nut from the pintail side at the same time and twist them to opposite directions, bolting operation is performed only at the pintail side. It simplifies the robotic system. Moreover, the pintail falls when bolt assembly ends, we can recognize the completion of the bolt assembly without other sensing devices.

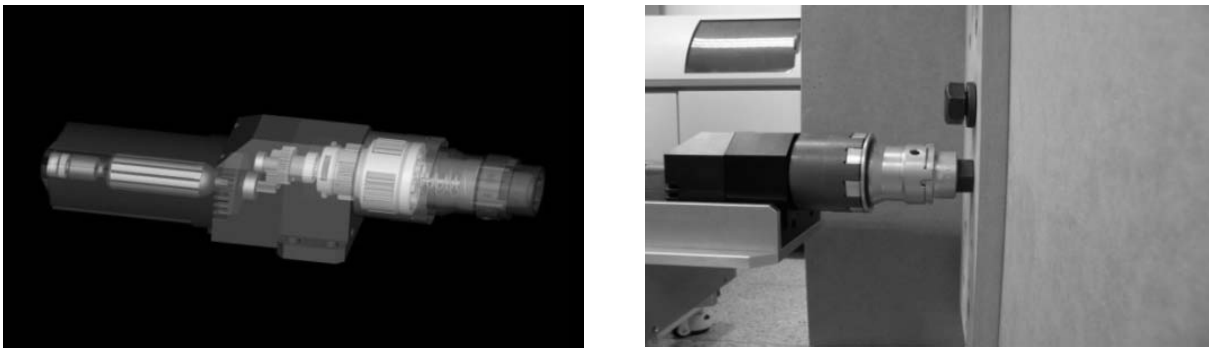
2.2 *Bolting end-effector*

A bolting end-effector is a device which operates the actual bolting task for TS type bolt. The bolting end-effector consists of DC motor, gear box, spring mechanism, and bolting parts. The bolting end-effector is actuated with a motor and a gear box to generate torque enough to fully assemble a bolt and nut pair. The pintail breaks when enough torgue is applied to TS type bolt and bolt assembly is completed. The pintail which remains in the bolting end-effector is detached outside when the bolting end-effector is pulled back. Figure 3 shows the 3D model and the prototype of the bolting end-effector.

Figure 2. TS type bolt.

2.3 *Robotic manipulator*

The robotic manipulator has a gantry type robot mechanism which has 3-DOFs. The bolting end-effector is attached at the end of the z-axis frame. The bolting end-effector is moved to the region of interest using this robotic manipulator. Figure 4 is the prototype of the robotic manipulator. The three frames of the manipulation system fit to three dimensional Cartesian coordinates, so that it can be easily controlled with a simple control algorithm. Using this robotic manipulator, the workspace of 830*830*300 mm^2 can be guaranteed and the accuracy under dozens of micrometers can be achieved. With consideration of the clearance between the diameter of the bolt and the size of the hole being approximately 2 mm, the accuracy of the robotic manipulation system is satisfactory [6].



(a) 3D model of the bolting end-effector. (b) Prototype of the bolting end-effector.

Figure 3. Bolting end-effector.

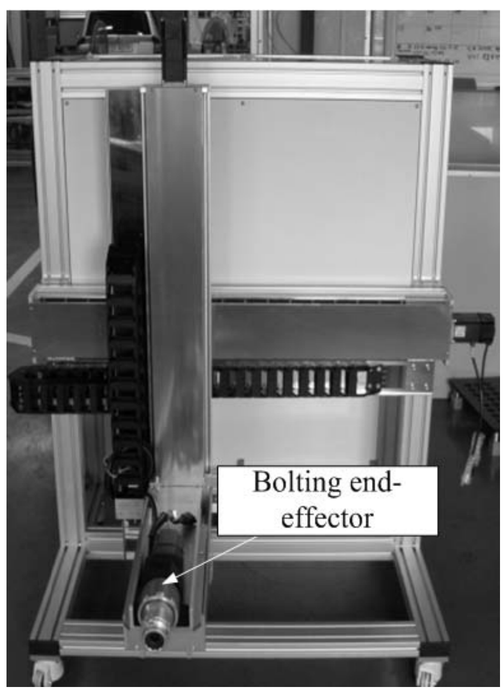
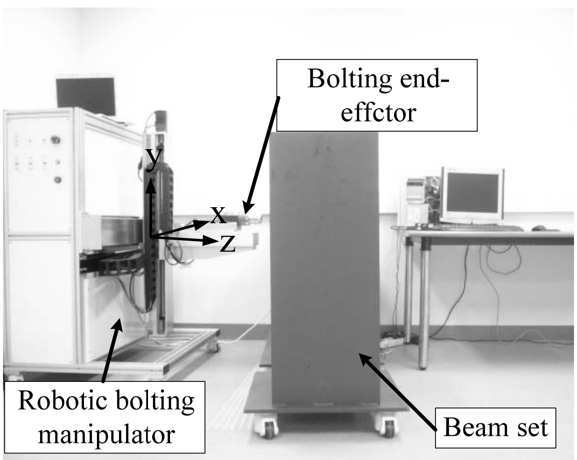


Figure 4. Prototype of the bolting manipulation system.

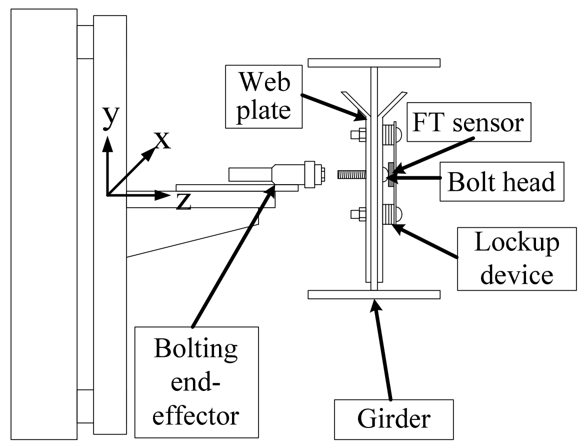
3. Experimental set for the robotic bolting assembly

Main purpose of this experiment is to determine the maximum feasible bolting angle between the girder and the robotic manipulator, and to examine supporting force of lockup device that prevents the bolt falling. Through the results of this experiment, we confirm feasible bolting criterions in bolting procedure using the robotic bolting device.

In order to replicate actual construction site in CF, an experimental set was made with a girder and web plate. The web plate is specially designed to align the beam and column automatically without an additional operation of an operator. Figure 5 (a) shows the experimental set which consists of the robotic bolting device, a girder/column assembly, and a FT(Force Torque) sensor. The FT sensor is attached to a lockup device that is placed on the opposite side of the robotic bolting device as shown in Figure 5 (b). The Bolting end-effector is placed on the bolting position by driving the x-y axis of the robotic bolting manipulator. And bolting is performed by proceeding z-axis of the gantry type robotic bolting manipulator and driving the bolting end-effector. We examined an acceptable bolting range between the girder and the robotic manipulator for successful bolting tasks. The FT sensor has direct contact with TS bolt head in order to measure the reaction force during the bolting process. Figure 6 shows relative angles between the girder and the robotic manipulator, where we marked 1 to 5 degree lines on the ground. Using these marks, we measured allowable relative angles between the girder and the robotic manipulator.



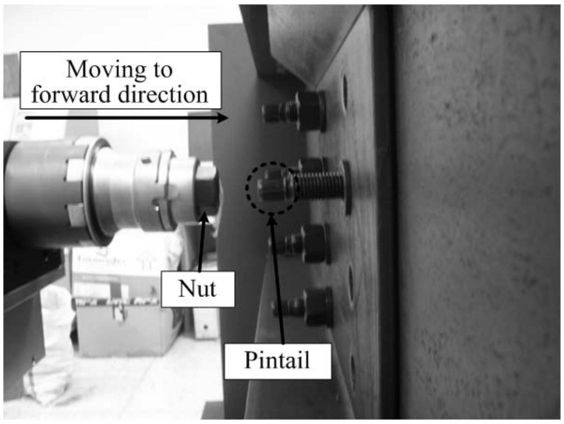
(a) Experimental set.



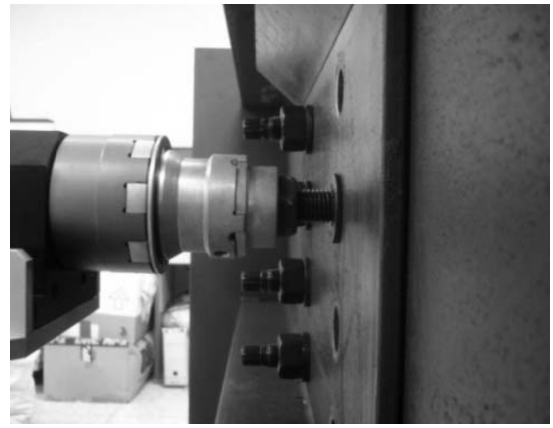
(b) Schematic diagram of experimental set.

Figure 5. Experimental set for measuring bolting reaction force.

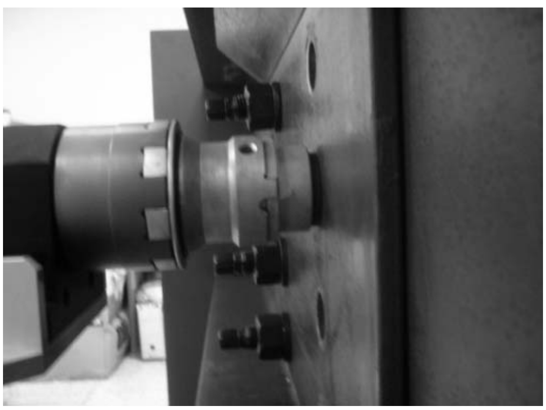
Figure 6. Relative angles between the girder and the robotic manipulator.



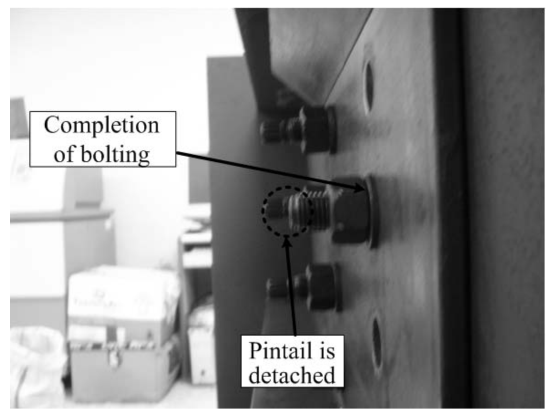
(a) The bolting end-effector is approaching.



(b) The pintail of the bolt is being inserted.



(c) the bolt and nut are being engaged.



(d) Bolting is completed.

Figure 7. Bolting assembly procedure.

4. Experiment and result

Figure 7 shows bolting experiment procedure. (a) The bolting end-effector is approaching the bolt. A nut is attached at the end of the bolting end-effector by magnet. (b) The pintail of the bolt is being inserted to the nut set on the bolting end-effector by proceeding z-axis of the gantry type robotic manipulator. (c) The bolting end-effector holds the nut and the pintail of the bolt at the same time, and twists them to opposite directions. And threads of the bolt and nut are engaged. (d) Bolting is completed and the pintail is detached. The proceeding speed of z-axis of the robotic manipulator is controlled to be the same as the feed rate of the bolt. Bolting experiments were repeated 10 times each with varying relative angles between the girder and the robotic manipulator from 0 degree to 5 degree.

Figure 8 shows reaction force measured by FT sensor with the relative angle of 4 degree. During Δt_1 ,, the bolting end-effector approaches the pintail of the bolt. Δt_2 is the period where the inserting and engaging task of the bolt and nut is performed. While the bolt and nut are being inserted and engaged, the z-directional reaction force increases and fluctuates. The force profile of Δt_3 in figure 8 shows that the reaction force is decreased after the engagement is completed. It means the bolting process is being done smoothly. In 4 degree of the relative angle between the girder and the bolting end-effector, the maximum reaction force to maintain the bolting task is 197N. Figure 9 (a) to (d) shows the bolting reaction forces according to the relative angles from 0 to 3 degree. In each case, the maximum reaction force is 48N, 101N, 124N, 155N. Reaction forces increase as the relative angle between the robotic manipulator and the girder increase. When the relative angle is more than 5 degree, the bolting task couldn't be performed. Therefore, the critical criterions for the successful bolting task using the robotic bolting manipulator are as follows: (1) The relative angle between the girder and the robotic manipulator is less than 5 degree. (2) The minimum force supporting the lockup device is more than 200N.

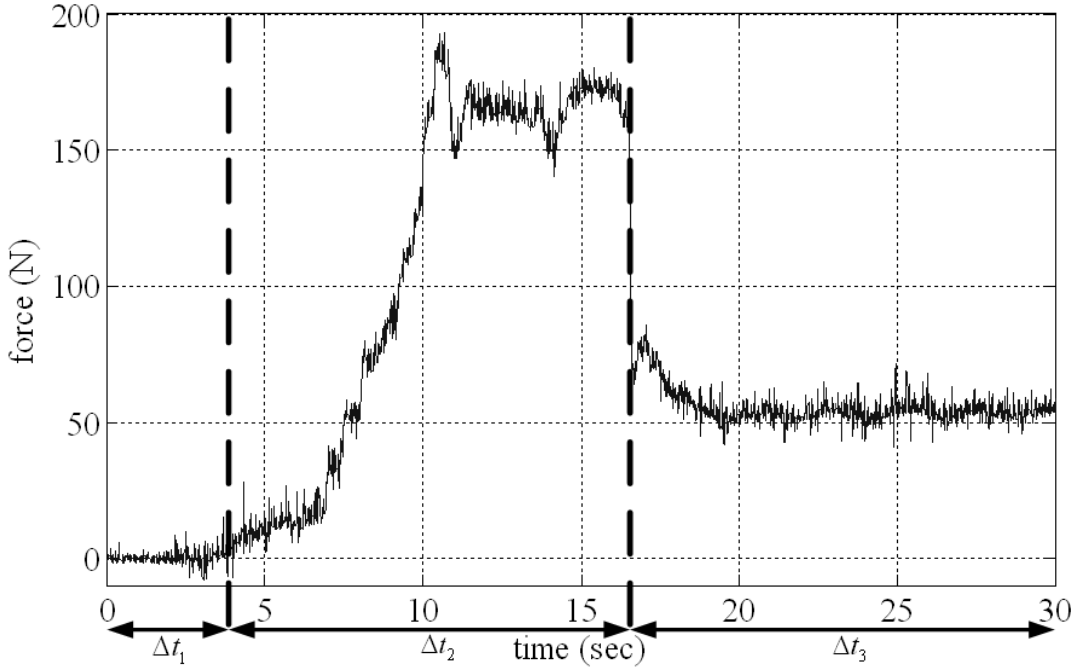
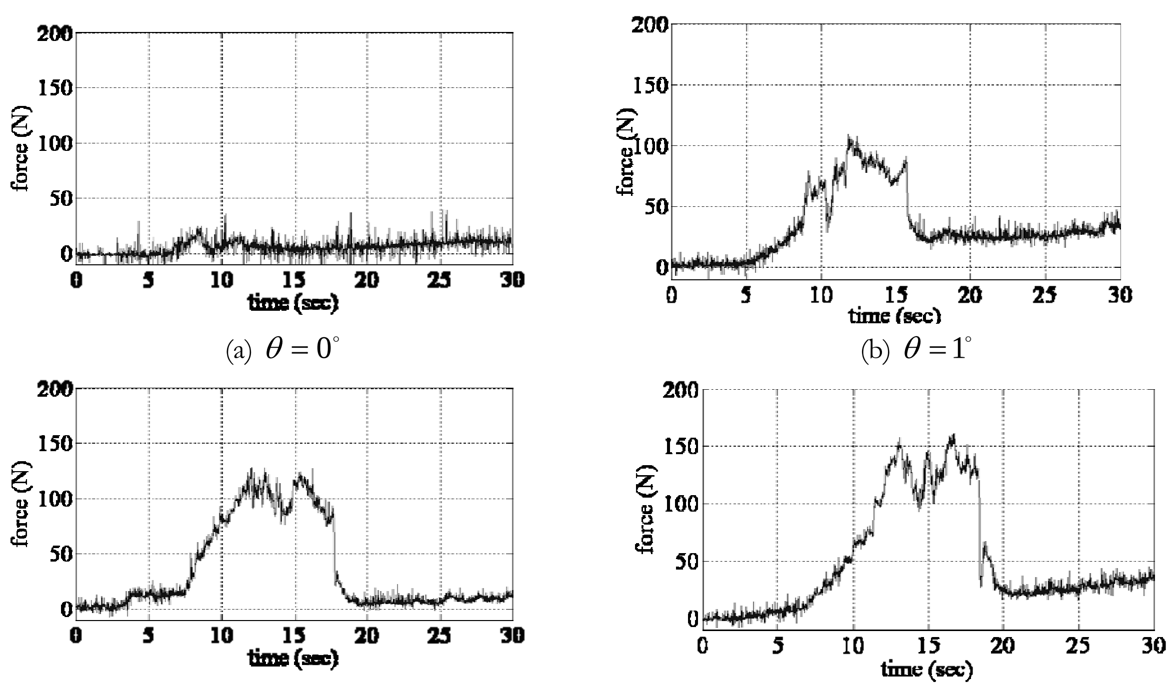


Figure 8. Experimental result. ($\theta = 4^{\circ}$)



(a) $\theta = 0^{\circ}$

(b) $\theta = 1^{\circ}$

(c) $\theta = 2^{\circ}$

(d) $\theta = 3^{\circ}$

Figure 9. Experimental results which has angles between the girder and robotic manipulator.

5. Conclusions

In this study, we obtained a force criterion and an angular criterion between the robotic bolting device and the beam to guarantee the successful bolting task. With various forces and angles, extensive experiments were performed to evaluate the feasibility of the bolting tasks using the suggested robotic bolting device.

The results attained by this research can be used to improve the performance of the developed robotic bolting device and develop an optimal version of the robot. Moreover, with employing the suggested bolting criterions, it is confirmed to control and operate the robotic bolting device safely and efficiently.

6. Acknowledgment

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References

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