Development of a Steel Beam Hauling System for Automatic Steel Beam Assembly

Ci-Jyun Liang[1] and Shih-Chung Kang[2]

[1]Master Degree Student; Computer-Aided Engineering Group, Department of Civil Engineering, National Taiwan University; 611, No.188, Sec. 3, Xinhai Rd., Da'an Dist., Taipei City 106, Taiwan (R.O.C.); PH (886) 2-3366-3366 #55263; email: polar@caece.net

[2]Associate Professor; Computer-Aided Engineering Group, Department of Civil Engineering, National Taiwan University; 607, No.188, Sec. 3, Xinhai Rd., Da'an Dist., Taipei City 106, Taiwan (R.O.C.); PH (886) 2-3366-4346; email: sckang@caece.net

ABSTRACT

During the assembly process of steel beams, the laborers must stand on narrow steel beams to assemble structures. Locating and bolting are two main steps in the steel beam assembly process. In the locating step, laborers haul and position the steel beam in the target position. In the bolting step, laborers assemble the steel beam with bolts. This manual assembly method can result in potentially fatal falling accidents. The efficiency of the process is also difficult to control. Therefore, we propose an autonomous joint system that will remove the need for laborers to work in elevated positions. The system consists of two subsystems: a steel beam hauling system, and a bolting system. In this study, we focus on the design of the steel beam hauling system. The steel beam hauling system can catch the draft cable using an electromagnet and haul the lifted steel beam to the target position. The cooperation between the system and the tower crane is also considered. The system can be attached to each steel column before erection then removed by the tower crane after the assembly process is finished. The system was built in a scaled-experiment construction site to test its feasibility. In conclusion, we propose an autonomous joint system that can help reduce accidental falls and improve efficiency of the steel beam assembly process.

INTRODUCTION

Steel beam assembly is always part of the critical path of a large high-rise construction project. Therefore, the steel beam assembly process influences the construction project schedule. To increase the safety and efficiency of steel beam assembly, this research aims to develop an appropriate system to aid in the assembly of steel beams. Erection and bolting processes account for a high percentage of the total cost of construction projects (Pavlovcic et al. 2004) and are extremely reliant on manual labor. Figure 1 illustrates the process of steel beam erection and assembly. First, the tower crane lifts and transports a steel beam to the assembly position as shown in Figure 1(a) and (b). Second, laborers align the steel beam to a precise position by hand, by draft cable, or even by foot, as shown in Figure 1(c). Finally, labors assemble the steel beam with steel plates and bolts as shown in Figure 1(d). During the process, laborers have to stand on a narrow steel beam in a high-rise location with only a simple safety cable. Accidental falls may occur and cause serious injury. Furthermore, the efficiency of the process is difficult to control because the work is completed manually.

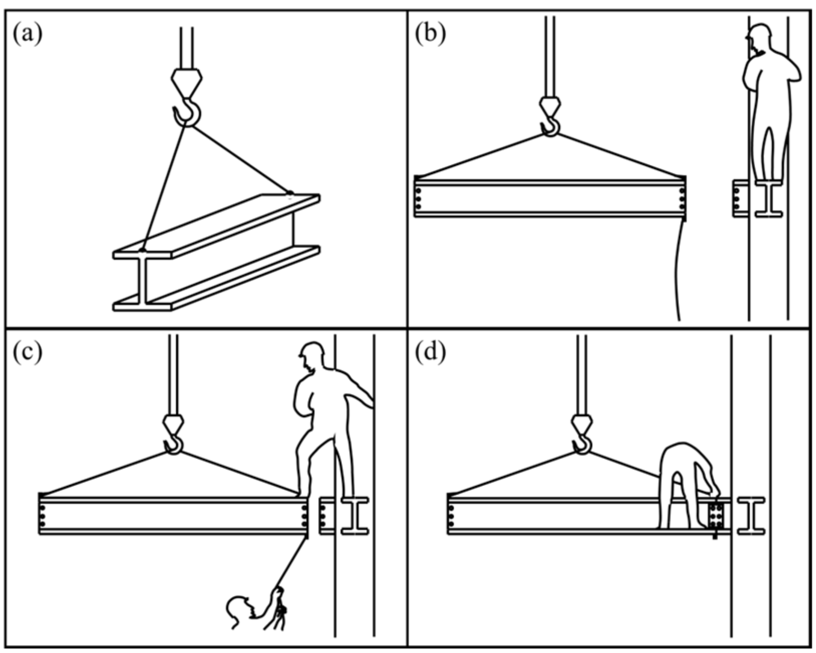

Figure 1. Steel beam erection and assembly process: (a) lifting, (b) transporting, (c) aligning, and (d) bolting.

Accidents at construction sites are serious. In Taiwan, more than six hundred accidents happen every year and cause hundreds of injuries (Chang et al. 2013).

Falls from high places, buildings collapsing and materials striking workers are three common types of accidents ("Occupational disaster statistics" 2010). Therefore, protecting human laborers is the primary goal to improve construction safety. Worker tracking and locating techniques have helped monitor laborers on construction sites and prevent accidents caused by blind spots (Lee et al. 2012; Park and Brilakis 2012). The next goal is to remove laborers from construction sites altogether. A remote control tower crane system has been used in an unoccupied construction site (Chi et al. 2012). Path planning algorithms were utilized to help transport steel beams without guidance from laborers at construction sites (Kang et al. 2009; Yoo et al. 2012; Zhang and Hammad 2012). Despite these technologies, laborers are still required in high-rise locations to assemble the elevated steel beams to the steel columns.

In order to achieve automatic steel beam assembly, a suitable manipulator must be developed. A scissor jack-type manipulator combined with a "construction factory" constructed automatic steel beam assembly has been developed (Chu et al. 2013; Jung et al. 2007, 2008, 2013). A Stewart platform crane can also provide a three-dimensional fully controllable manipulator (Vincent Viscomi et al. 1994). These systems were large and heavy, requiring a great deal of time to assemble and deliver. Therefore, we propose a small and simple autonomous joint system for steel beam assembly. The proposed autonomous joint system is intended to improve the safety and efficiency of steel beam assembly. Removing laborers from construction sites during steel beam erection and assembly processes will prevent falls and accidents due to falling material. In addition, the assembly efficiency can easily be controlled since the manual human factor has been excluded from the process.

SYSTEM OVERVIEW

As previously discussed, locating and bolting are the two main steps in the steel beam assembly process. Therefore, a steel beam hauling system and a bolting system have been designed for use in an autonomous joint system. Figure 2 shows the system architecture. First, the tower crane will lift the steel beam and move it close to the target position. Next, the steel beam hauling system will catch and haul the lifted beam exactly into position. Then, the bolting system will assemble the steel beam with steel plates and bolts. Finally, the tower crane will remove the system and move to the next position until the task is completed. In this study, we focus on the design of the steel beam hauling system.

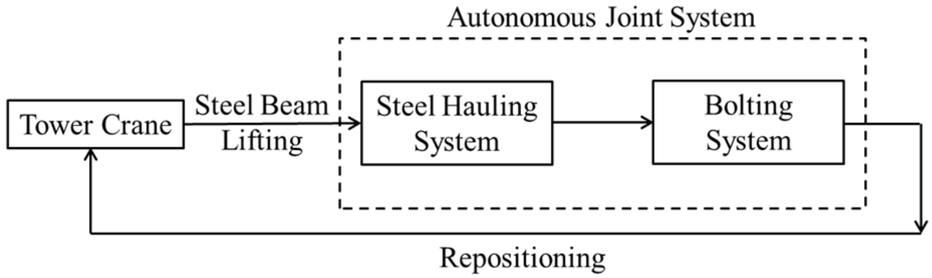

Figure 2. System architecture.

SYSTEM DESIGN

The main purpose of the steel beam hauling system is to haul a lifted steel beam to an assigned position. The system is equipped with a cable-catching device and a rolling device, as shown in Figure 3. When the lifted steel beam approaches, the system will catch the draft cable using an electromagnet on a rolling bar. The rolling bar then rolls the draft cable up to haul the steel beam to the target position. Figure 4 illustrates the working process of the steel beam hauling system.

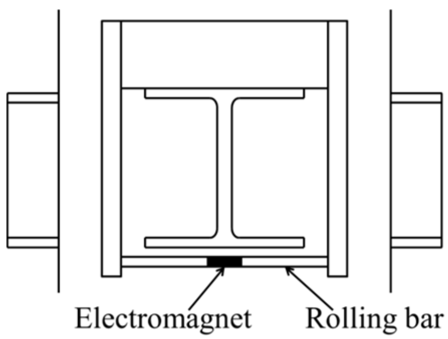

Figure 3. Cable-catching device and rolling device.

Two different types of the system were designed. The first is the clothespin type, for which the system is attached to a column by a clothespin-shaped mechanism. Two rods provide push and pull forces to tighten and release the system. When the steel beam approaches the target position, an aligning mechanism will clip to the steel beam and adjust it to a precise position, as shown in Figure 5(a). The system will be attached to each steel column before erection. After the tasks are completed, the system will be transported to the next working position by the tower crane.

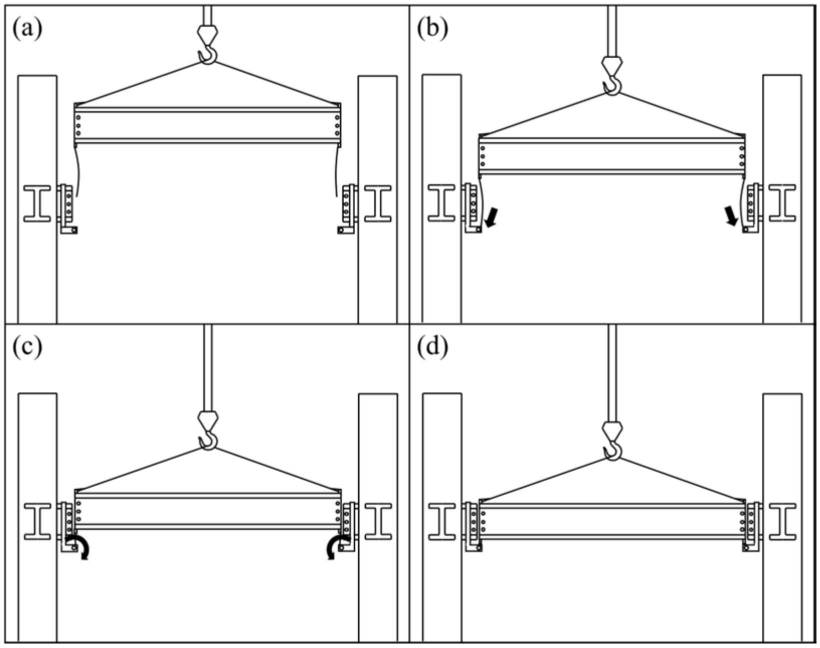

Figure 4. Steel hauling system working process: (a) approaching, (b) catching, (c) rolling, and (d) orientating.

The second type of system is the crab clip type and is shown in Figure 5(b). This system is attached to a beam-column joint by a crab-clip shaped mechanism. The crab clip is tightened by an internally driven cable. The aligning mechanism is replaced by a self-aligned beam-column joint to reduce the weight of the system. The system will be attached to each beam-column joint before the erection process begins and will be removed by the tower crane after the steel beam assembly tasks are finished.

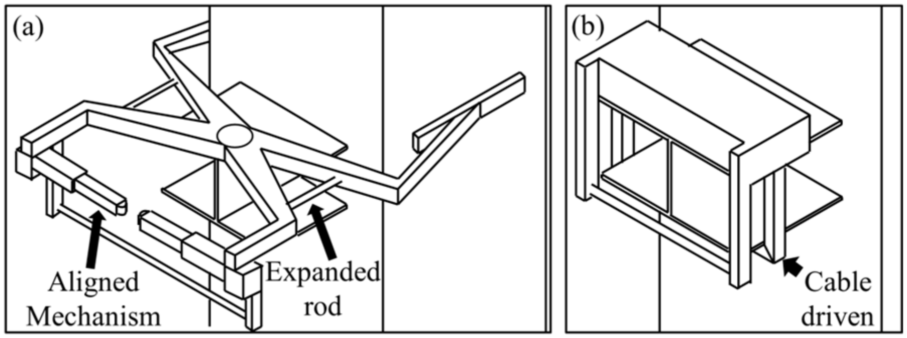

Figure 5. Steel beam hauling system: (a) clothespin type, and (b) crab clip type.

The steel hauling system was built in a scaled-experiment construction site to test the feasibility, as shown in Figure 6(a). A KUKA KR 16 CR robot arm was used as a tower crane. The system prototype was made by LEGO Mindstorms NXT, and is shown in Figure 6(b). PITSCO TETRIX were used as steel beams and columns. The 'catching' and 'rolling' steps were performed with an approximately 80% success rate. The primary cause of failure was loosening of the draft cable separated from the rolling bar during the hauling task. It was also revealed that the algorithm controlling cooperation between the system and the tower crane needed to be developed further. Moreover, a more specific feasibility test must be done in the future.

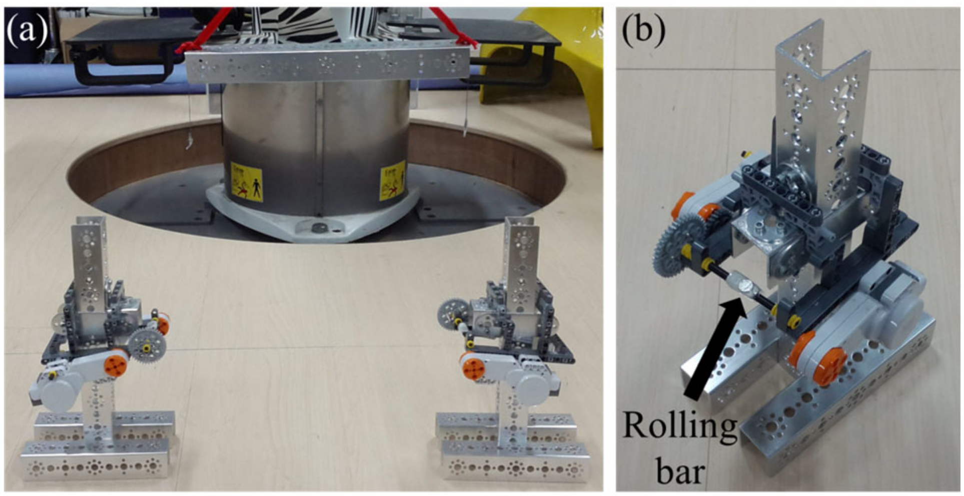

Figure 6. Steel beam hauling system feasibility test: (a) scaled-experiment construction site, and (b) system prototype.

CONCLUSION

An autonomous joint system for steel beam assembly has been proposed. The steel beam hauling and bolting subsystems are the two main parts of the autonomous joint system. The system hauls the lifted steel beam to the joint assembly position. The system is intended to replace human laborers in high-rise buildings. This could reduce accidental falls as well as improve the efficiency of steel beam assembly. Future work includes development of the bolting system, integration of the two main systems and systematic test.

REFERENCES

Chang, C. C., Wen, S. H., and Huang, Y. J. (2013). *Safety evaluation for high-rise scaffolds and mast climbing work platforms*. Institute of Occupational Safety and Health, Taiwan.

Chi, H. L., Chen, Y. C., Kang, S. C., and Hsieh, S. H. (2012). "Development of user interface for tele-operated cranes." *Advanced Engineering Informatics*, 26(3), 641–652.

Chu, B., Jung, K., Lim, M. T., and Hong, D. (2013). "Robot-based construction automation: An application to steel beam assembly (Part I)." *Automation in Construction*, 32, 46–61.

Jung, K., Chu, B., Bae, K., Lee, Y., Hong, D., Park, S., and Lim, M. T. (2008). "Development of automation system for steel construction based on robotic crane." *International Conference on Smart Manufacturing Application*, Kintex, Gyeonggi-do, Korea, 486–489.

Jung, K., Chu, B., and Hong, D. (2013). "Robot-based construction automation: An application to steel beam assembly (Part II)." *Automation in Construction*, 32, 62–79.

Jung, K., Kim, D., Bae, K., and Hong, D. (2007). "Developement of the gripping control algorithm for wire-suspended object in steel construction." *24th International Symposium on Automation and Robotics in Construction, ISARC 2007*, Madras, India, 151–155.

Kang, S. C., Miranda, E., and Chi, H. L. (2009). "Three-dimensional simulation and visualization of crane assisted construction erection processes." *Journal of Computing in Civil Engineering*, 23(6), 363–371.

Lee, H. S., Lee, K. P., Park, M., Baek, Y., and Lee, S. (2012). "RFID-based real-time locating system for construction safety management." *Journal of Computing in Civil Engineering*, American Society of Civil Engineers, 26(3), 366–377.

"Occupational disaster statistics." (2010). *Council of Labor Affairs*, http://www.cla.gov.tw/site/business/41733649/4226b8a3/4e15159a/files/%C2%BE%B7~%A8a%AE%6099m43~50.xls (Nov. 6, 2012).

Park, M. W., and Brilakis, I. (2012). "Construction worker detection in video frames for initializing vision trackers." *Automation in Construction*, 28, 15–25.

Pavlovcic, L., Krajnc, A., and Beg, D. (2004). “Cost function analysis in the structural optimization of steel frames.” *Structural and Multidisciplinary Optimization*, Springer-Verlag, 28(4), 286–295.

Vincent Viscomi, B., Michalerya, W. D., and Lu, L. W. (1994). “Automated construction in the ATLSS integrated building systems.” *Automation in Construction*, 3(1), 35–43.

Yoo, W. S., Lee, H. J., Kim, D. I., Kang, K. I., and Cho, H. (2012). “Genetic algorithm-based steel erection planning model for a construction automation system.” *Automation in Construction*, 24, 30–39.

Zhang, C., and Hammad, A. (2012). “Improving lifting motion planning and re-planning of cranes with consideration for safety and efficiency.” *Advanced Engineering Informatics*, 26(2), 396–410.