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Construction Automation: A Drywall Robot

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Abstract
The construction industry in the United States is suffering from a serious labor shortage. A viable solution to the labor shortage is the use of fewer workers to perform routine tasks. Therefore, the use of robots became appealing. To date, efforts have been aimed at the development of the ultimate robot (self-contained, self-learning, multi-functional, super-intelligent). In other words, efforts have focused on the creation of a robot that resembles a human worker rather than development of simpler, more achievable robots that eventually may evolve into the ultimate robot. A literature review reveals that the industry's high expectation of robotics was not met during the last decade. The industry's expectations were not met because of overly ambitious robot designs while overlooking necessary changes in facility design. This paper presents specifications for a smart Robot used to install drywall. The machine is easy to control and requires minimal skill to operate. A production comparison was made between a typical drywall crew and a crew using the Robot. The Robot provided significant productivity improvement. It is also anticipated that the use of the Robot will save money as it significantly reduces the physical demand required in drywall installation.

Keywords
Construction, Automation, Robotics, Drywall, Sheetrock Installation

1. Introduction

The development of robots for use in the construction industry has been prompted by the current and projected shortage of skilled labor coupled with the need for maintaining quality and quantity despite the employment of less skilled workers. Owners and contractors are searching for solutions to this serious problem. A viable solution to the labor shortage problem is using fewer workers by finding a means for gaining significant improvement in productivity. With the successful use of robots fewer workers will be needed, standardized production will ensure quality, and improved productivity is possible. A literature review provides a large number of articles published on robotic applications in construction (Cousineau and Miura, 1998; Lee et al. 1998; Huang and Bernold, 1994; Bernold, 1993; Rihani and Bernold, 1996; Zhang et al. 1997; Rosheim, 1994; Rehg, 2000). Applications of robot use on construction sites have been attempted for a number of activities. Examples include shotcreting (Cheng and Wey, 2000), clinker clearing (Haas et al. 2000), and painting (Bai and Bernold, 2001). The design of these robots was largely driven by the need to decrease worker exposure to certain activities such as noise, dust, hazardous substances and dangers from poor visibility. Routine tasks such as painting, bricklaying, sheetrock installation and similar activities are prime areas of exploration.

Currently, the application of robots in the construction industry is more prevalent in Europe and Asia. European and Asian constructors have invested heavily in research and development of robots. On the other hand, universities have largely conducted robotics research in the United States with minimal participation and funding from the industry. To date, efforts have focused on the creation of a robot that resembles a human worker rather than the development of simpler, more achievable machines that eventually can evolve into the ultimate robot. A literature review reveals that the industry's high expectations of robotics for construction operations were not met during the last decade (Boles and Wang, 1996; Bernold, 1998). Researchers and developers did not satisfy the industry's expectations for two primary reasons: 1) overly ambitious robot designs while 2) overlooking the necessary architectural and structural changes in facilities design. Overly ambitious robot designs led to major technical problems prior to gaining enough expertise in that field of science. Overlooking the necessary changes in facilities design added to the technical difficulties as robots were expected to perform more complex tasks that resulted in a disconnect between the robot's capabilities and its field applications. Since full robotics of construction operations is highly complex and multidisciplinary it requires comprehensive short-term and long-term plans. In the short-term, a desired operation should be broken down into simpler, more attainable tasks or functions. In the long-term, the simpler tasks or functions are integrated to achieve a more intelligent, self-directed robot, as the challenges in each task are resolved and perfected.

Drywall installation involves measurable physical activities that have a toll on productivity. The activities expose laborers to physical exertion that can ultimately lead to worker injuries and claims. A typical drywall installation involves picking up sheetrock, placing it against studs and securing the material to the supporting studs. This involves a systematic set of movements that can be simulated by a robot. On commercial projects a significant amount of labor hours are spent hanging and attaching sheetrock to studs. The repetitiveness, weight, reach and load-thrust make this operation a prime candidate for automation.

This paper presents a study focused on construction robotics. A sheetrock robot is presented as a viable solution that has high potential for assisting the construction industry in meeting its goal of doing more work with fewer workers. The purpose of this study was to propose an external design and specifications for a Robot used to install drywall. The objective was to achieve a machine that is easy to control and that would require minimal skills to handle. The Robot is compact and fit for commercial construction. It is also anticipated that this robot will improve worker retention by making the drywall installation less physically demanding.

2. Design Considerations

The design philosophy employed by the research team contained the goals of keeping the operation simple and avoiding total elimination of labor activities. This philosophy was adopted to ensure the creation of a practical robot and to avoid possible labor force resistance to the idea of automation of construction work. The introduction of new technologies that has the effect of reducing the number of workers on a project has been meet with resistance by labor organizations in the past. Protection of existing jobs is generally of paramount concern, but improvement of working conditions is generally favored. Many design parameters were taken into account during the design process and several alternatives were examined. Among those were the detailed motions or steps involved in sheetrock installation, size limitations of the robot, and its maneuverability. Alternatives were analyzed for appropriateness in most common field conditions for commercial construction. The expected productivity was assessed and compared to the industry's common practice production rate of manual labor installing sheetrock.

The installation process of sheetrock was broken down into its most basic steps. The first step was the storage of sheetrock material. Several methods were examined. The initial thought was to attach a trailer to the Robot to provide a sufficient supply of material to minimize restocking. However, this made the Robot unnecessarily long and difficult to maneuver through openings and around corners. Another alternative examined was to place a lesser amount of sheetrock on the robot itself. This resulted in an oversized and bulky Robot with limited maneuverability. To maximize maneuverability, it was decided that the machine would not haul or carry material at all. Instead, the industry's common method of transporting sheetrock using a stand-alone dolly would be used in conjunction with the Robot. Dollies could be easily restocked and distributed by a laborer, who could support several Robots simultaneously.

The second step was to choose the hoisting mechanism to lift the drywall sheet and place it in its target location. Two hydraulic arms were selected as the lifting and placement device. Hydraulic power systems have more flexibility than mechanical or electrical systems and can produce more power than other systems of equal size. Hydraulic power also provides rapid and accurate responses to controls. The use of a hydraulic system is essential to provide the required movement when combined with the weight of a drywall sheet. The system would use a rotary motor. In a rotary motor the pressurized fluid supplied by the hydraulic pump acts on the surfaces of the motor's gear teeth, vanes, or pistons thereby creating a force that produces torque on the output shaft. This force is transferred to pistons that are used to extend and lift the hoisting arms.

The third step was to identify the retrieval mechanism used to recover drywall sheets from the dolly. In evaluating the possible recovery mechanisms, the research team considered the difficulty in separating one sheet from a stack, the required sensitivity of the system to avoid damaging the drywall sheets, and ease of positioning a sheet in its final location. A system of suction cups was chosen. The machine picks up each sheet using a suction cup installed at the end of each of two lifting arms. This retrieving mechanism will cause no damage to sheetrock, eliminate problems associated with attempting to pick a single sheet of drywall from the stack, and would require only simple operational movement. It was also decided that cutting of drywall sheets would be left to the operator or laborer to simplify the design of the proposed robot. The cutting operation would needlessly complicate the operation of the Robot.

The fourth step was to determine the process of securing the sheet in place. It was decided that this machine would only place screws. This decision was made because the robot is intended for commercial application. To place screws, a screw gun, similar in operation to a nail gun, is used. The screw gun is mounted on a hydraulic arm, which has the capability to move up, down, right and left. The arm carrying the screw gun is mounted between the two lifting arms. (See Figure 1). The screw gun first secures the screws in the four-foot distance between the two lifting arms. The lifting arms could then be retrieved back, and the screw gun would proceed to place the remaining screws. It was decided to limit the degree of freedom of the arm handling the screw gun. Because of this limitation, the screw gun is mounted on a track and also utilizes an expanding telescopic arm. The combination provides significant up and down movement. The gun would also be able to move forward and backward using a small telescopic arm for fine adjustment in positioning. The screw gun arm is mounted on a second track to allow for full right and left movement along the whole width of a drywall sheet. The screw gun arm is equipped with a metal stud detector for verifying screw placement. The operator would input data such as stud spacing and screw placement spacing to facilitate the placement of screws. The operator would verify the location of the first stud and maneuver the screw gun into its first position. The Robot would then be able to place the remaining screws based on the initial reference point and data entered by the operator. Once all the screws have been placed, the operator would retract the screw gun arm and the lifting arms. The operator could then direct the machine to place the next sheet.

In choosing the type of energy used to power the Robot, the work environment was considered. The Robot would primarily perform indoor activities. Therefore, diesel and gas engines were eliminated. Battery-operated electric motors and liquid natural gas (LNG) fired engines were examined. It was decided that the Robot would use a LNG fired engine in order to optimize the Robot's weight, refueling effort, refueling cost, and time between refueling.

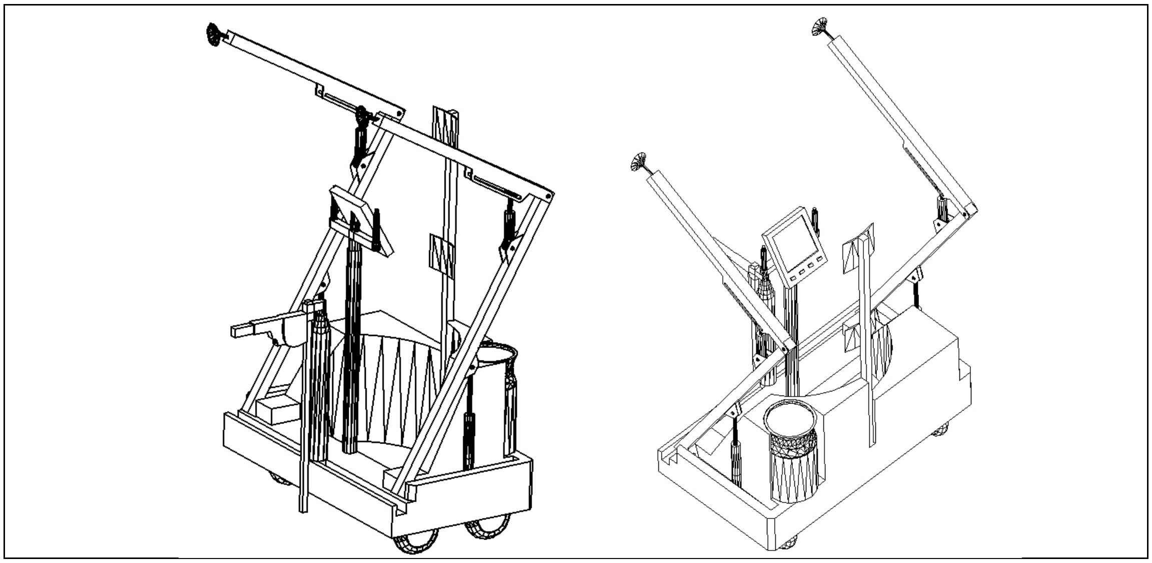

Figure 1*:* The smart vehicle

Various mechanisms for lateral movement of the Robot were examined. Initially, three points of contact with the floor was suggested. However, four wheels were used in the final design to improve the balance of the Robot. In addition, the research team examined other possible capabilities that might easily be added to the Robot. Activities such as taping, floating, painting, and plastering could easily be addressed by providing additional attachments. For example, paint attachments could include a paint gun system with multiple paint heads that could be mounted in place of the screw gun.

3. External Specifications

Upon the determination of the above design considerations, the Robot's external specifications could be developed. The external specifications are the description of the critical dimensions and components of the robot.

A liquid natural gas (LNG) engine was chosen for its efficiency. The LNG's high-octane makes it highly fuel efficient with high power and quick response. A quick response is essential when performing the movements necessary for proper positioning of the Robot and delicate handling of sheetrock. Clean-burning propane is a suitable fuel for closed working conditions. Maintenance should be minimal, as propane burns cleanly, leaving almost no deposits that cause wear and tear on engine components. Fueling is easy, simply exchanging an empty bottle of propane for a full one.

Determination of the Robot's weight is important for a number of reasons. The weight must not impede nor limit the functionality of the Robot, or cause damage to work surfaces. Weight and weight distribution, including the operator and hoisted material, affect the Robot's stability. To determine the Robot's weight, each component's weight was estimated separately. The estimated weight of the proposed Robot is approximately 1,600 pounds including the additional live loads of operator and sheetrock material. The weight was divided into front, middle, and back areas for proper weight distribution. Table 1 shows the weight and distribution of the major components.

Table 1: Smart Vehicle Weight Breakdown

Part Description	Weight (lbs)	Distribution		
		Back	Middle	Front
Operator, human	180	100	80	
Sheet 1/2" Drywall	80			80
Solid Core Rubber Wheels and Steel Base	248	89	69	90
Propane Tank w/ propane and Battery	81	81		
LPG 20hp Motor and covers	165	145	20	
Hydraulic Pump motor and tank	80	55	15	10
Back Rest and Control Station	70	30	40	
Main Lifting Arms and track	440	15	70	355
Nail Gun and Drive Train	205			205
Total	1549	515	294	739

4. Components Description

The dimensions of the Robot were chosen to allow easy maneuvering through a standard doorway. This limited the width of the Robot to 2'- 6" and its height to 6'- 8". The Robot would have to fit in a standard elevator for transportation between floors. The robot's platform (base) is a 1/4" steel plate, which is 2'-3" wide by 4'-3" long. This compact size allows the machine to easily maneuver through a standard door. The steel plate provides the rigidity of the Robot. The platform supports the motor, fuel tank, and electronic/control devices. (See Figure 1).

The machine places screws with the use of a self-feeding system. The gun itself will be similar to self-feeding hand operator systems currently available from several large manufacturers. The gun is mounted on a track, which in turn is mounted on a telescoping base. The telescoping base allows the unit to be raised to the height necessary to place screws at the ceiling level. The telescoping base can raise the screw gun to a height of twelve feet. However, when the base is collapsed to its most compact position, it is only 2'-8" above the floor. To reach the lowest section of the wall, the telescoping base collapses to its lowest point. At that point, the screw gun is able to travel downward along the fixed track. The track allows the gun to be positioned 6" above the surface supporting the robot to permit securing the lower portion of the wall. When reaching a lower elevation is required, the operator or laborer supplying the material would install the screws manually.

The operator controls the operation of the machine from the central control panel. (See Figure 1). The control panel is mounted on an adjustable base in front of the operator. The central control panel contains three parts. The first part is the operating keyboard where controls used to turn the machine on/off and move the robot forward, backward, and laterally are located. The second is the data screen. The data screen allows the operator to input information such as wall height and stud and screw spacing. The third part of the control panel contains the joysticks. There are two joysticks, one on each side of the data screen. The operator uses the joysticks to control the movement of the hydraulic arms and the movement of the screw gun. There is a backrest stand that provides lower and upper back support for the operator.

5. Productivity

To further evaluate the capability of the Robot, its productivity was assessed and compared to labor production rate for drywall installation. Means Cost Manual (Means 2002) was used to determine labor productivity for sheetrock (4' x 8' of 1/2") installation. Utilizing the Means' rate, a crew of two carpenters working eight hours a day can install 2000 square feet per day. This daily rate results in an installation rate per person of less than 4 sheets per hour, or approximately 15.3 minutes per sheet. To assess the productivity of the robot, each movement of the Robot was conservatively estimated to determine its ideal cycle time. An operation factor of 45 minutes per hour was used to determine the Robot's adjusted cycle time. The adjusted cycle time using the robot is 5.3 minutes per sheet. The Robot saves of 10 minutes per sheet, providing additional justification for the expenditures required to own and operate the robot.

6. Conclusions

The proposed Robot is a practical solution to the current and projected labor shortage. The Robot was designed to lift and place sheetrock and to attach placed sheetrock to studs utilizing screws. It does not replace all human workers, nor would it be desirable to do so. Instead, it simplifies the process and removes heavy lifting work from the operator, thus making hanging drywall faster and easier. It will decrease medical problems associated with heavy lifting. The elimination of repetitive, hard physical work should reduce labor fatigue and thus result in productivity improvement. The machine is designed to hang sheetrock to a height of twelve feet and is capable of maneuvering through a 2' - 6" doorways. Several possible features could be easily added to increase the versatility of the robot. These include painting, taping, and floating. The researchers recommend that further research be conducted and ultimately a prototype of the proposed Robot be built.

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