Mechatronic Approach to an Intelligent Machine: the Case of an Assistive Device

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Abstract. Today, one of the most important research fields is concerned to the Engineering Design Process, which is focused on designing better electro-mechanical systems with a low impact on the environment and a most efficient use of the energy. Currently the design process can take advantage of many computational-aided tools, which play a key role in the modern methods of optimization and reduce the cost of prototyping. This work presents the design process of an assitive device implementing a mechatronic approach. The mechanical design is carried out, as well as the electronic and control. The integration of all the modules of the system is done with the use of a graphical user interface to give easy access to manage and control the entire system.

Keywords: Intelligent machine, mechatronics, assisted device, hospital bed

1 Introduction

In response to medical requirements presented by hospitals and more important by patients, new mechanical devices must be designed to fulfill successful healthcare services. One of the devices that most impact has is the hospital medical bed [16, 15]. Several mechanical designs of hospital beds have been proposed to alleviate the very intensive labor and the lack of qualified personal (nurses and stretcher-bearers), mainly in developing countries. In Ching-Hua [4] a hospital bed with auxiliary functions of lateral positioning and transferring patients is described. Three mechanisms are described which assist in complicated maneuvers of moving patients from hospital beds to the stretcher.

Andhare [1] makes a design that attempt is to reduce the amount of assistance required in managing these patients. Special focus is made on the mechanism synthesis stage. Kittipichai [8], proposed an optimization procedure for the structure design of a hospital bed using genetic algorithms. The novelty of the bed structure is that it can support the left and or right leg for patient's leg splint.

Some goals of the design are to reduce the mass of the bed structure. In the work of Shih-Wei [14] the Mechanism Design and Mechatronic Control of a Multi-functional Test Bed for Bedridden Healthcare is presented. The design considers two beds, one main bed, and one nursing bed with transferring capabilities. A remarkable feature is that the designed bed is built by mechatronic engineers and qualified healthcare personnel simultaneously.

Kap-Ho [7] presents the development of an intelligent bed robot system, which is a particular bed equipped with two robot arms and an array of pressure sensors attached to the mattress capable of estimate the pose of the patient.

Mohammed [9] present a new design of a Multi-Functional Portable Patient Bed which is used to carry and transfer a patient's body. The most interesting novelty of the approach is that the design is demand-based, i.e. the proposed design of the bed is formulated based on literature survey as well as consult the medical staff.

This design approach for the hospital bed goes beyond, and it is based on Latin-American patients, nurse and stretcher-bearers demands. Hospital human resources are the people in daily contact with real situations and needs. For this reason, their feedback is essential to producing a useful hospital bed. This renders the basis to consider a functional set of positions demanded by real bed needs. Then, for each required position a mechanism synthesis stage brings a solution for the motion of each required tool. Finally, using tools of mechanical engineering, the complete design can be developed. It is important to mention that the bed construction involves the design and manufacturing of various areas (mechanical, electronic, industrial and graphic design). This integration produces a functional device in combination with an intelligent system [3].

2 Mechanical Design

This section describes the positions and special feature requirements achieved by a serious study at Hospital Juarez de México (HJM) over two months of applying our diagnostic methodology [16, 15]. About three hundred medical experts were asked to define such requirements. As a benchmark for the requirements, Latin-American patients' height was considered as an essential part of the design process, see [2].

2.1 Positions

Several hospital bed manufacturers provide a broad range of models that are suitable either for intensive therapy or hospitalization. Depending on specific requirements, some positions are rendered by each bed model. The most common configurations are orthopedic, cardiac, fowler and Trendelenburg. Nevertheless, other useful positions are foot elevation, panning or tilting and sit, [5]. From the universe of possible position, our proposal provides twelve positions based on the results of our study in HJM and their medical requirements. All these positions are depicted in Figure 1.

Fig. 1. Twelve required positions for the hospital bed

It is important to indicate that home position implies vertical motions that render the adjustable height of the hospital bed. To achieve the desired positions, different mechanisms were synthesized to provide the desired ranges of motion. Such ranges were also obtained by an ergonomic study carried out at the Center for Investigation in Industrial Design (CIDI-UNAM), see [11].

2.2 Special Features and Functions

Traditionally, specialized functions are offered by manufacturers as a concrete and expensive extensions of standard models of hospital beds. Nevertheless, our approach is to satisfy the requirements of the market, i.e. the users of the bed.

The results obtained from our study in the Hospital Juárez of México, indicate the necessary requirements to work in all possible scenarios. It also provided information about the usage by the hospital people and maintenance of a hospital bed. From these results, we defined a list of general requirements that must be fulfilled to achieve an appropriate working relationship and successful using of this specialized medical device.

Also, to satisfy this feature set, additional considerations complying with IEC-60601-52 standard were taken into account. The final set is listed below:

- Ensure the stability of the device in any of their positions.
- For security, no user should have contact with mechanical parts.
- The railings must have free movement in any position.
- Access controls should be comfortable and live (even without electric energy).
- Access medical peripherals and accessories must be free and comfortable in any position.
- The position of the device should not limit the use of peripherals.
- It must attend medical user to find the right position for the patient in different circumstances given by the condition of the patient.
- The rails and feet-board should allow visibility of the medical staff at any time should obstruct patient monitoring.

- Should allow access for perform common tasks toilet.
- Ensuring stability in patient transfer conditions on the device, even with two more people on it.
- The device should provide a good service (maintenance) to the user during their stay in hospital.
- It must make the patient's stay comfortable taking into account as far as possible the emotional aspect of it (eg, sense of stability and safety during movements).
- It should avoid, prevent and/or minimize any risk both use and health for all users, especially for the patient
- A safety loading of 3000 [N], corresponding to two patients of an average weight of 150 Kg, must be resisted by the mechanical structure.
- A minimum and maximum height of 47 cm and 90 cm must be provided by the bed. It will be useful for the Help to stand-up position.

2.3 Mechanism Synthesis

To simplify the mechanism synthesis, a group of subsets of the mechanism is described below. It is important to indicate that to render appropriate motion to each mechanism linear actuators of specific trademark were selected due to it certification with the International Standard IEC-60601-52, which is the standard dedicated to electrical beds. Mechanism synthesis is performed by using the required ranges of motion for each position obtained by the ergonomic study [11], then by using standard optimization methods and working on mechanism analysis [13].

Figure 2.3 shows the mathematical model used to synthesize the elevation mechanism. Using the standard notation for mechanism analysis, the six bar mechanism responds to the following set of equations.

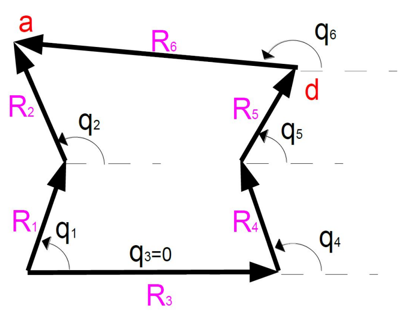


Fig. 2. Schematic of the lifting mechanism

Base The base of the bed must provide enough stability to prevent falls by a patient or any other from the bed in rest and handling. Our device must not cause any dangerous situation for the patient's health. To reaching our objectives, a rectangular base is proposed as shown in figure 2.3, coupled with the elevation mechanism.

To render mobility to the bed a set of four Tente © castor Wheels were firmly attached to the base. Moreover, they have the function of directional brake or total brake to ensure the safety of the patient when the bed is in the rest.

Lifting Mechanism This mechanism consists of two slider-crank mechanisms coupled to a six bar mechanism which allows vertical and longitudinal displacements of the sectioning mechanism. The lifting mechanism is also responsible for Trendelenburg and anti-Trendelenburg positions, and it is mounted on the base of the robotic bed, as in Figure 3.

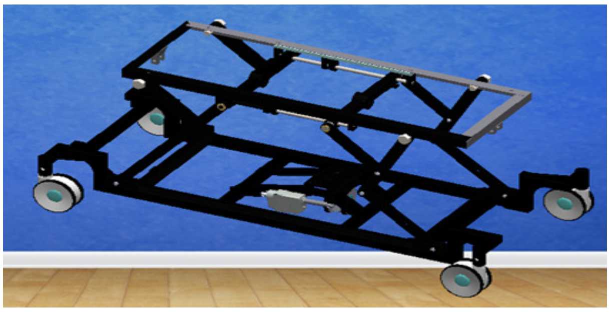


Fig. 3. Lifting mechanism for the hospital bed

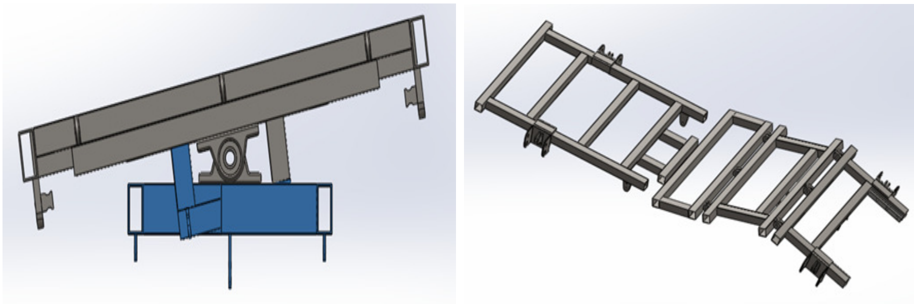
$$r_1 e^{\mathbf{j}q_1} + r_2 e^{\mathbf{j}q_2} = r_3 e^{\mathbf{j}q_3} + r_4 e^{\mathbf{j}q_4} + r_5 e^{\mathbf{j}q_5} + r_6 e^{\mathbf{j}q_6} \quad (1)$$

where $e^{\mathbf{j}q_i} = \cos(q_i) + \mathbf{j}\sin(q_i)$. In this mechanism, all vectors r_i are constant while the angles q_i are time varying.

Note that when $q_6 = 0$, components in direction $\mathbf{Y}$ of points a and d in figure 2.3 are at the same elevation. Moreover, their Cartesian positions can be described using model 1. By using the minimum and maximum height of 47 [cm] and 90 [cm], a set of angular position constraints can be defined. Next, using standard mechanism synthesis tools the elevation mechanism is completely specified by selecting the length of the links.

Tilt Mechanism This mechanism is directly coupled to the elevation mechanism by six SAE-grade 1 screws and nuts.. Its motion is controlled by a slider-crank mechanism with a special linear actuator, coupled to a hinge-like mechanism, see figure 4(a).

This mechanism causes the sections mechanism to rotate in the sagittal plane of the bed. Thus, it handles the Right and Left tilt positions in Figure 1.



(a) Tilt mechanism (b) Sections mechanism

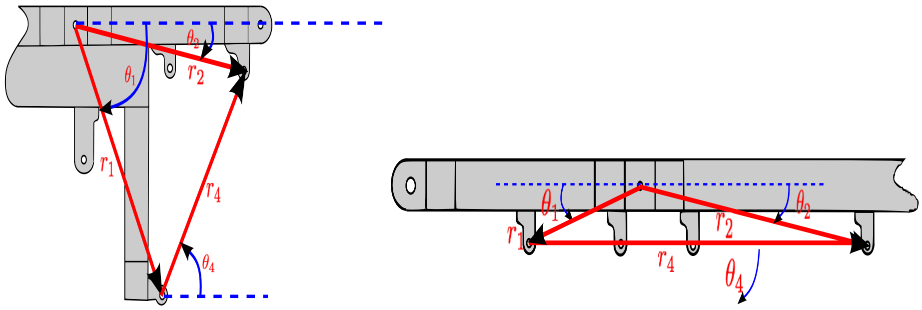
Fig. 4. Tilt an Sections for the Hospital Bed

Sections Mechanism Figure 4(b) depicts the sections mechanism. It is a set of hinge-like open chain mechanism where the whole body of the patient must rest. The first link of this open-chain mechanism corresponds to the backrest, which is coupled to the slide-guard mechanism, described in the next section. In the second link of the sectioning mechanism the patients' hip rests. This link is welded to the tilt mechanism. The third and four links correspond to the legs and feet mechanisms, respectively. The whole mechanism is isolated in figure 4(b).

Leg Mechanism This section is designed as an inverted rod-cranck mechanism, see 5(a). The equations modeling this mechanism are

$$r_2 e^{\mathbf{j}q_2} = r_1 e^{\mathbf{j}q_1} + r_4 e^{\mathbf{j}q_4} \tag{2}$$

In this case, vector r_1 is fixed while vector r_4 represents a linear actuator which render a rotational motion to vector r_2 through angle q_2.



(a) Legs mechanism (b) Feet mechanism

Fig. 5. Mechanisms in the hospital bed to care lower extremity

Feet Mechanism This section is also designed as an inverted rod-cranck mechanism, see figure 5(b). The equations modeling this mechanism are

$$r_2 e^{\mathbf{j}q_2} = r_1 e^{\mathbf{j}q_1} + r_4 e^{\mathbf{j}q_4} \tag{3}$$

In this case, vector r_1 is fixed while vector r_4 represents a linear actuator which render a rotational motion to vector r_2 through angle q_2. Note that, vectors r_1 and r_2 are fixed. Moreover, vector r_1 is fixed at the legs section.

Slide-guard Mechanism This mechanism is a slider-crank coupled to the backrest link of the sections mechanism, see Figure 7. The kinematic model for this mechanism is described by equation 4. Then, the synthesis stage follows the procedure as for the elevation mechanism.

$$r_1 e^{\theta_1} + r_4 e^{\theta_4} = r_2 e^{\theta_2} + r_3 e^{\theta_3} \tag{4}$$

The design of this mechanism is motivated because it allows to adjust the size of the bed while the backrest is moving. To the best of the authors' knowledge, this mechanism is the first of this kind implemented in a robotic hospital bed. To determine the slider dimension, an ergonomic study was carried out, see Figure 6.

In this study, the backrest and hip sections were studied to obtain a linear displacement between them which renders comfortable motion and less stress for the back of the patient.

It concludes that it is required to consider a transfer of 11 [cm] linear adjustment mechanism at the hip section, (regardless of the setting of the backrest in degrees). If this is considered, anthropometric needs of an average Mexican population are covered, from female to male percentile 5 to percentile 100, [11].

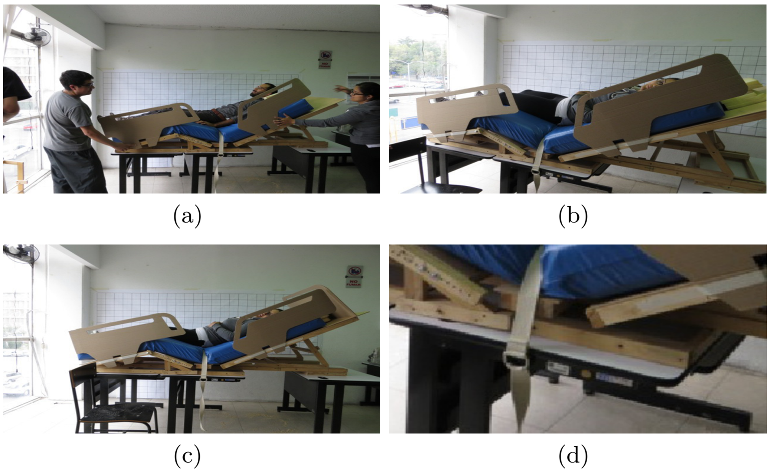


Fig. 6. Some positions of the ergonomic study for the robotic bed.

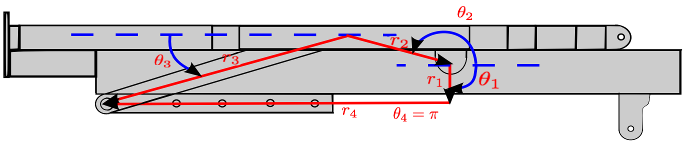


Fig. 7. Slide-guard mechanism for the hospital bed

Railings Mechanism Railings are designed as a four bar mechanism. The main objective of this mechanism is to keep each railing in vertical position tin order to guarantee patient's safety, as depicted in Figure 8.

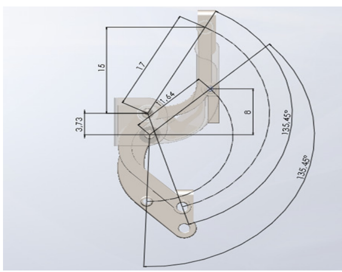
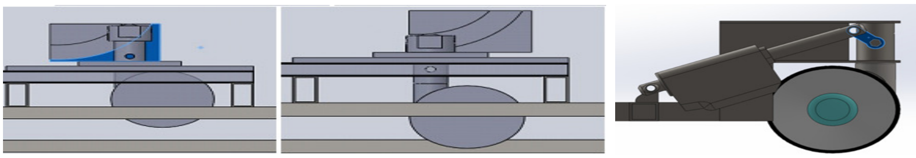


Fig. 8. Railings mechanism for the hospital bed

Fifth-Wheel Mechanism The goal of the fifth-wheel is to improve the maneuverability of the robotic bed while transporting a patient. For this reason, the fifth-wheel is only active during any transportation task. The mechanism is a cam coupled to a slider-crank mechanism. This allows to deactivate the fifth wheel when the bed is in the rest, see figure 9(a).



(a) Fifth-Wheel (b) Brake mechanism

Fig. 9. Additional mechanisms in the hospital bed

Brake Mechanism To guarantee the whole robotic bed stay in rest, a brake mechanism is required. This mechanism is provided by the set of four Tente© wheels. Our design only considered a bar to activate the brake on each pair of wheels as shown in figure 9(b). The bar is coupled to a slider-like mechanism.

2.4 Mechanical Design Methodology

For the design and selection of the machine and structural elements of the robotic bed, the resistance and rigidity criteria were selected. This is because no high velocities are considered. Thus, a static behavior can be assumed. The resistance criterion in mechanical design establishes that there is not any mechanical element that will overcome its elastic limit behavior, thus guaranteeing that fault will not appear, i.e. the material does not break down. The rigidity criterion establishes that the deformations due to the loads on any mechanical element will not stay within the elastic limit of the selected material, thus ensuring that no permanent deformations will appear.

Both criteria allow us to determine the geometry and the material of each mechanical element of the structure of the robotic bed.

For the structure of the bed, the standard A-36 standard steel was selected in this stage of prototype manufacturing. This material has excellent welding properties and it suitable for cutting, grinding and a variety of well-known manufacture processes.

Considering this material as a specification for the design, SolidWorks © was used to draw and perform finite element analysis to the geometries of the robotic bed. Square profiles were selected as the geometry of the structure. As the A-36 steel is ductile, the Von-Misses main strains were selected as the resistance criterion. This analysis considered 3000 [N] of the mechanical load as required. Nevertheless, it is omitted in this paper due space constraints.

The final render of the mechanical design obtained is depicted in figure 10.

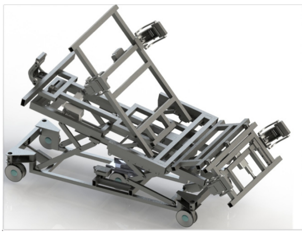
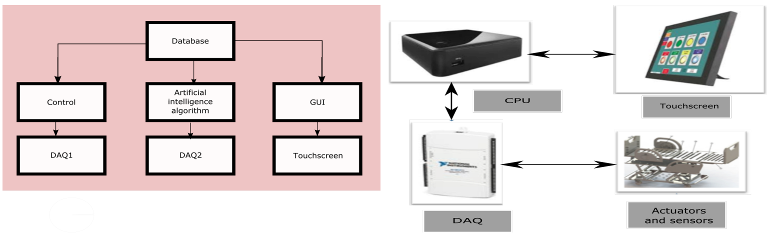


Fig. 10. Final

3 Control

This section presents how the software components interact to achieve the desired behavior specified by the user. They communicate between them trough a database. Figure 11(a) shows the architecture of the control system where the three different parts of this device are shown. Part 1 is the communication with the control system responsible for giving overall mobility; this is done by through the DAQ. Stage 2 is the distribution processing system and means with which it has to interact with users through artificial intelligence algorithm. Finally, in step 3 GUI where the end user can interact with the physical system through the touchscreen shown. In Figure 11(b) is displayed as the entire system is constituted physically.



(a) (b)

Fig. 11. Flow and physical diagram

4 Integration using a GUI

In constant operation of the lifting mechanism, measured position is presented in the graphical interface, and it must display the real position of the physical system. Therefore, the user must have real information to observe and handle the variables in the machine. Additionally, this development takes into account the implementation of a function call [6],to isolate the design and constructibility of the GUI. Therefore, this work is done considering the flexibility of the entire system.

In Figure 12 is presented a screenshot with all the elements available to the final user. The guidelines of multi-modal interface design [12] and cognitive decision approach [10] were taken into account to finally obtain the showed distribution in the GUI.

This picture contains an interactive way to manage the positions of the system with easy handle method. The combination of colors was selected by considering different situations of usage and the variety of the user that are going to be interacting with the system.

(a) (b) (c)

Fig. 12. GUI

5 Conclusion

Our diagnosis methodology is a way to perform the identification of the assistant robotics needs in a hospital; this leads to the identification of opportunity areas for the development of robotic devices. It is important to have a methodology that assures that the solutions proposed respond to real needs. This method can be applied to rehabilitation engineering and the clinical fields providing concrete solutions to the most critical needs detected in hospitals. Once a technical proposal is qualified as viable according to our methodology, the robot or the assistant device can be manufactured.

In this work was presented a successful appliance of a mechatronic approach to the assistive robot. The mechanical structure was synthesized according to the needs identified previously. The mobility of the robotic mechanism renders the required positions while comfort and patient's safety is guaranteed. The full design will allow to integrate mechanical and electronic components together with industrial design, resulting in an affordable device.

The intelligent system applied in this work shows a strategy to endow robotic assistants ability to detect risk scenarios to patients. In this case, when the robotic bed is moving can generate situations of risk if patients perform any bodily movement that is inappropriate to such a step. This represents an advance in medical care since through such devices can treat patients without medical personnel does not risk an injury when moving patients personally. In this case, the robotic bed can be programmed in such way the appropriate medical personnel may attend to other patients while applying certain movement therapy automatically by medical monitoring. Although our bed is working correctly, currently a second version could be carried out to attain the reduction in costs, improvement in manufacturing and integrating processes and to include some other functions to the device.

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