Development of an instrumented mannequin for training of caregivers in safe patient handling and movement

Oneida Dugarte Westhoff

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Development of an Instrumented Mannequin for Training of Caregivers in Safe Patient Handling and Movement

by

Oneida Dugarte Westhoff

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering Department of Electrical Engineering College of Engineering University of South Florida

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Date of Approval:
March 16, 2004

Keywords: biomedical engineering, ergonomics, biomechanics, patient safety, nursing, goniometer, flex sensor, pressure sensor, labview

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DEDICATION

To my daughter, with all my love and life, for being patient with me when I didn’t have enough time to share with her. Nathaly, I love you.

To my family, although they are far from me, they will always be with me in my prayers. I love you so much.

To my husband Wayne, who is my inspiration, for supporting me all the way. Thank you, TAM.
ACKNOWLEDGMENTS

Support for this project was provided by Patient Safety Research Center, James A. Haley Veterans' Hospital, Tampa, Florida.

A special ‘Thank you’ to John Lloyd, Wilfrido Moreno, James Leffew, Andrea Baptiste, Shawn Applegarth, Eduardo Zurek, and Luis Navarrete for all their advise and support on this project.
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A common problem associated with patient handling is the risk of bodily injury due to acute or cumulative trauma. The objective of this research was to develop an integrated solution, using commercially available components, to help health care providers handle patients in a safe manner. The objective was achieved by retrofitting a mannequin with flex sensors, electrogoniometers, pressure sensors, and photocells. The sensors were capable of quantifying angular displacement, skin pressure distribution and undignified exposure. All of these variables were monitored by a computer-based data acquisition system. The design of this integrated system was implemented using National Instruments LabView software, which possessed the capability to provide both spasm simulation process control and a history of the acquired sensor data.

A virtual instrument, (VI), was developed using LabView as the interface between the user or instructor and the instrumented mannequin. The VI had the capability of displaying the history of the acquired data. With access to the data’s history the trainer is able to analyze the sensor information and verify the procedural
accuracy of the actions performed on the simulated patient by the student. The system technologies employed can help the instructor improve the training of health care workers. Additionally, providing the trainer with useful information about the student’s skill building during interaction with a patient enhances evaluation of the student’s performance.

Once the data is collected, the instrumented mannequin is capable of identifying problems such as excessive force or pressure when health care providers are interacting with patients. This provides the healthcare community with useful information to improve and provide a safer and more comfortable environment for the patient.

The instrumented mannequin will be a valuable tool in evaluating and assessing the merits of clinical procedures. It may also be used in biomechanical studies involving patient handling by caregivers.
CHAPTER 1

INTRODUCTION

1.1 Introduction

A common problem associated with patient handling is risk of bodily injury due to acute or cumulative trauma. The objective of this research was to develop an integrated solution using commercially available components to help health care providers handle patients in a safe manner. The objective was achieved by retrofitting a mannequin with flex sensors, electrogoniometers, pressure sensors and photocells. The sensors were capable of quantifying angular displacement, skin pressure distribution and undignified exposure. All of these variables were monitored by a computer-based data acquisition system.

1.2 Quality Patient Care

Many health groups support the plan of establishing a safe environment of care for caregivers and patients [1]. Patient handling such as lifting, repositioning and transferring has to be performed by skilled health care workers. The performance of these tasks exposes caregivers and patients to increased risk of physical injury [1]. In addition, there might be circumstances when patients are agitated, aggressive, unreceptive or can offer limited levels of assistance, which
increase the risk for injury. With the development of patient handling equipment, such as lift and transfer devices, the risk of injury to patients and caregivers can be significantly reduced [2], see Figure 1. Effective use of equipment and devices for patient handling creates a safe healthcare environment by reducing the physical demands on the caregiver and heightening/improving the safety, comfort and dignity of the patient [1].

Technology and specialized equipment currently exists in industry to assist with patient handling. Examples of patient handling equipment are presented in Appendix A. The level of effectiveness for using patient handling equipment and devices to prevent patient and caregiver injuries is a function of availability, maintenance and sufficient space. Equipment and devices must be available to caregivers in order to encourage their use. This was one of the goals of “The Instrumented Mannequin”, a project developed by the University of South Florida and the Patient Safety Research Center at James A. Haley Veterans' Hospital in Tampa Florida.
A study of any patient lifting and moving task involves an evaluation of the needs and abilities of the patient. The evaluation allows health care workers to study the patient characteristics. Additionally, the evaluation determines the safest method for performing a task that provides appropriate care and service for the patient. The patient evaluation should include examination of factors such as [3]:

1. The level of assistance the patient requires
2. The size and weight of the patient
3. The ability and willingness of the patient to understand and cooperate
4. Any medical conditions that may influence the choice of methods for lifting or repositioning.

These factors are important in determining the appropriate method for lifting and moving a patient. The size and weight of a patient will establish the equipment requirements and the number of caregivers required to provide the assistance [3]; see Figure 2.

Figure 2: Safe Patient Handling
1.3 Dignity and Care of the Patient

One of the fundamental objectives for health care professionals is respecting the patient’s dignity. Patients want to be treated as human, not simply as a body with a disease. Respecting the patient’s dignity requires that caregivers provide careful, knowledgeable and helpful medical care to the patient according to the training that health workers have received [4].

A patient’s perception of appropriate dignified handling may be influenced by religious and ethical values. An examination that was once acceptable may become unacceptable or improper in another period of time based on cultural/religious setting of the patient. Health care workers face special difficulty in trying to balance their knowledge with varying religious and ethical values. For example, patients may feel that doctors have behaved improperly during an intimate examination. Examinations may also be stressful and embarrassing for patients [4], [5].

Doctors should explain certain factors, to the patient, before performing an examination. Some of these factors are [5]:

Make clear why an examination is necessary

1. Clarify, in a manner that he/she can understand, which factors the examination will involve
2. Get the patient's permission before the examination
3. Suggest to the patient that he/she can have a relative or friend present during the examination
4. If the patient needs to undress or dress, provide him/her the required privacy.

5. Use long curtains to maintain the patient's dignity.

Table 1 presents data from an exploratory study in a medical school that was performed to study whether students followed the procedures during intimate examinations [6].

Table 1: Recollection of Consent Obtained Before Examination of Anaesthetized Patients [6]

<table>
<thead>
<tr>
<th>Year of Study</th>
<th>Examinations performed</th>
<th>Written Consent</th>
<th>Oral Consent</th>
<th>Not Known if Consent was given</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>For named Student</td>
<td>For Any Student</td>
<td></td>
</tr>
<tr>
<td>Second</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Third</td>
<td>128</td>
<td>0</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Fourth</td>
<td>563</td>
<td>162</td>
<td>6</td>
<td>356</td>
</tr>
<tr>
<td>Total</td>
<td>702</td>
<td>162</td>
<td>6</td>
<td>368</td>
</tr>
</tbody>
</table>

The data presented in Table 1 shows that the students conducted a total of 702 intimate examinations. However, only 24% of the examinations had the patient's permission. An additional 24% of the examinations were performed without written or oral approval [6].

This data presented in Table 1 clearly shows that students must be responsible in requesting the patient’s permission prior to performing any examination. Additionally, these results show that some students were uninformed about their ethical and legal responsibility to obtain the patient’s permission. This study suggests that doctors have to be sure that an approval was obtained and that students are ready to follow all the standards procedures applicable when performing clinical examinations [6], see Figure 3.
1.4 High Risk Patient Handling Task

High-risk patient handling tasks are always present when caregivers work with any patient. Some tasks, for example, transferring from bed to chair or from chair to bed, might involve high-risk activities if good technical procedures and equipment are not used correctly, see Appendix A. The difficulty of the movement task will vary depending of the dependency level of the patient [8]. Examples of patient handling tasks are presented in Figures 4 and 5.
Figure 5: Typical Patient Handling Tasks [9]
An instructional manual titled “Patient Care Ergonomics Resource Guide: Safe Patient Handling and Movement” was produced by the Patient Safety Center of the Veterans Hospital to reduce the frequency of work injuries related to patient handling and movement. This document offers guidelines that concentrate on patient evaluation issues and proposes solutions for patient lifting and repositioning problems [7].

Different patient handling techniques must be used accurately to prevent caregivers and patients from getting injured. Some studies related to patient handling techniques suggest that caregivers should plan in advance the activities that will be required to carry out the task. The plan should be constructed in such a manner that the patient is handled with more subroutines instead of executing the entire technique in one continuous routine.

Most importantly, the instructional manual, “Patient Care Ergonomics Resource Guide: Safe Patient Handling and Movement, enumerates the most demanding tasks in evaluation order [7]:

1. Transferring patient between toilet and chair
2. Transferring patient between chair and bed
3. Transferring patient from bathtub-to-chair
4. Transferring patient from chair lift-to-chair
5. Weighing a patient
6. Lifting a patient up in bed
7. Repositioning a patient in bed side-to-side
8. Repositioning a patient in a chair
9. Changing an absorbent pad
10. Making an occupied bed
11. Undressing a patient
12. Tying supports
13. Feeding a bed-ridden patient
14. Making an unoccupied bed

The investigators from the Patient Safety Center at the Veterans Hospital documented that the following nursing tasks are also high risk [7]; see Figure 5.

1. Bathing a patient in bed
2. Making an occupied bed
3. Dressing a patient in bed
4. Transferring a patient from bed to stretcher
5. Transferring from bed to wheelchair
6. Transferring from bed to dependency chair
7. Repositioning a patient in a chair
8. Repositioning a patient in bed
9. Applying anti-embolism stockings (TED hose)

The key to preventing injuries to caregivers and patients lies in conducting a proper ergonomic/biomechanical evaluation of the work place. The objective of the evaluation is to analyze job tasks and discover high risk factors that can jeopardize health care workers or patients. “The Instrumented Mannequin” was created to train caregivers in safe patient handling in order to reduce the potential
for injury. This technology provides the healthcare community with useful
information to improve and provide a safer and more comfortable environment for
both the patient and caregiver.
CHAPTER 2

BACKGROUND THEORY

2.1 Measurement of Joint Motion

Health professionals use a technique called goniometry to determine joint angle measurements. The measurement of joint motion is very significant in the physical evaluation of the extremities and spine of a patient [11]. Through joint motion examinations doctors can evaluate dysfunctions and provide the patient with an appropriate rehabilitation program. This concept will be studied in detail in the next section.

The joints permit the articulation and movement of the bones. Joints can be grouped into three different classes depending on their structure [13]:

1. Fibrous: The least mobile joint
2. Cartilaginous: The medium mobile joint
3. Synovial: The most mobile joint.

In both fibrous and cartilaginous joints the articulate surfaces of the two bones are joined by connective tissue. However, in synovial joints the articulate surfaces are not directly connected [13]. Figure 6 presents an example of the synovial class of joint.
2.1.1 Basic Definitions

The basic definitions involved with the study of the measurement of the joint are presented in this subsection.

2.1.1.1 Planes and Axes

The surface motion of a joint is described in three planes, which are termed the sagittal, frontal and transversal. These planes are associated with three axes, which are termed the medial-lateral, anterior-posterior and vertical [11], [12]. The sagittal plane possesses the following characteristics:

1. Advances from the anterior to the posterior portion of the body
2. Divides the body into right and left halves
3. Flexion and extension motions are described in the sagittal plane.

The axis that is perpendicular to the sagittal plane is called medial-lateral axis [11]. Figure 7 presents an example of the sagittal plane.
The frontal plane divides the body into front and back halves [11], [12]. The frontal plane possesses the following characteristics:

1. Advances from one side of the body to the other
2. Abduction and adduction motions are described in the frontal plane and occur around the anterior-posterior axis.

Figure 8 illustrates the frontal plane.
The transverse plane is horizontal and divides the body into superior and inferior parts [11]; see Figure 9. The transverse plane has the following characteristics:

1. Motions that occur in this plane are rotation of the head, shoulder and hip. Also, the motions of pronation and supination of the forearm occur in this plane.

2. The vertical axis is perpendicular to the transverse plane.

![Figure 9: Transverse Plane [11]](image)

### 2.1.1.2 Goniometry

Norkin and White [11] states that:

“The term goniometry is derived from two Greek words, *gonia*, meaning angle and *metron*, meaning measure. Therefore, goniometry refers to the measurement of angles. In particular, the measurement of angles created at human joints by the bones of the body“.

The instrument used to measure angles is called a goniometer. Figure 10 presents an example of different mechanical goniometers.
To operate a goniometer, position each arm along the centerline of a segment across a joint. Figure 11 presents an example of how to place a goniometer to determine an angle measurement.

**2.1.1.3 Biomechanics**

Biomechanics is the study of the body in terms of its mechanical structure and properties. Stated in another way, biomechanics studies the forces that act on limbs [21].
2.1.1.4 Range of Motion

Range of motion, (ROM), refers to the extent of motion of a joint and can be measured in any plane [11], [12]. The measure of the ROM at a joint is influenced by factors such as age, sex and whether the movement is executed actively or passively. Flexion/extension and hyper-flexion/extension are two terms that are used when describing a joint’s ROM. The term flexion/extension refers to the movement that returns from the full flexion/extension to the zero initial position. The term hyper-flexion/extension refers to the movement that is greater that the normal flexion/extension motion [11]. Figure 12 presents an example of these concepts.

![Figure 12: Flexion/Extension to/from Zero](image)

2.1.1.5 Active Range of Motion

The active range of motion, (AROM), is the range of movement realized during the voluntary motion by a person. AROM provides the clinician with information
about coordination, muscle strength and the willingness of the patient to move. The AROM has tends to be less than that realized passively [13].

2.1.1.6 Passive Range of Motion

The passive range of motion, (PROM), is the range of movement realized by a clinician without any contribution from the patient. In this movement each joint permits an extra amount of movement because the patient is calm and does not help in producing the motion. Therefore, passive range of motion is normally greater than the active range of motion [11], [13].

2.1.1.7 Validity and Reliability

Information that is collected is valid and reliable if it represents meaningful values of the data [11], [13]. Norkin and White state that [11]:

“Validity refers to how well the measurement represent the true value of the variable of interest”.

In other words, the validity of an angle measurement is the value that represents the actual joint angle that was measured.

Furthermore, Norkin and White state that [11]:

“Reliability is the consistence between successive measurements of the same variable, on the same subject, under the same conditions”.

Stated in another manner, angle measurements of a joint are reliable if every time that the measurements are taken their values yield the same results.

To maximize reliability it is recommended that the examiner use standardized
test positions, use the same amount of force that is applied to the body and employ the same measuring devise to minimize variability between measurements [13].

2.2 Biomechanics of the Knee

This subsection presents a study of the anatomy and range of motion of the knee joint. Evaluation of the range of motion is also included.

2.2.1 Anatomy of the Knee

The knee joint is the largest and most complex joint of the human body. The knee joint is composed of two distinct articulations, which are performed by the tibiofemoral and patellofemoral joints [13]; see Figure 13. The tibiofemoral joint links the femur and the tibia. The patellofemoral articulation is between the posterior surface of the patella and the patella surface of the femur [13]. The location of the knee, between the two longest bones of the body, makes it more vulnerable to injury.

![Figure 13: The Knee Joint [12]](image-url)
2.2.2 Range of Motion of the Knee

The range of motion at the tibiofemoral joint is described in three planes. The biggest ROM is in the sagittal plane [12]. This joint has two degrees of freedom. The total motion of the joint from extension to full flexion is approximately 140 degrees. Flexion and extension motions are located in the sagittal plane around a medial-lateral axis. The rotation is located in the transverse plane around a vertical axis [13]; see Figure 14. Table 2 presents an example of the different ROMs of the knee in diverse activities.

![Figure 14: Range of Motion of the Knee Joint](image)

Table 2: Knee Flexion Range of Movement Required In Various Activities [13]

<table>
<thead>
<tr>
<th>Activity</th>
<th>Max Range of Flexion Required (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking</td>
<td></td>
</tr>
<tr>
<td>Slow (stance phase)</td>
<td>65</td>
</tr>
<tr>
<td>Free (stance phase)</td>
<td>5</td>
</tr>
<tr>
<td>Fast (stance phase)</td>
<td>15</td>
</tr>
<tr>
<td>Running (stance phase)</td>
<td>20</td>
</tr>
<tr>
<td>Ascending Stairs</td>
<td>105</td>
</tr>
<tr>
<td>Descending Stairs</td>
<td>105</td>
</tr>
<tr>
<td>Sitting Down</td>
<td>90</td>
</tr>
<tr>
<td>Tying shoes laces</td>
<td>105</td>
</tr>
</tbody>
</table>

As described in Table 2, a person walking fast or running produces maximum range of flexion for the knee joint in the neighborhood of 20 to 30 degrees. If the
person is sitting down the maximum range of flexion is 90 degrees. Further, the maximum range of motion that a person experiences is 105 degrees, which occurs when tying shoe laces.

2.2.3 Evaluation of Range of Motion of the Knee

This sub-subsection explains the correct procedure for measuring the flexion and extension in the knee joint. Additionally, a description of how to align the goniometer is included.

2.2.3.1 Flexion and Extension of the Knee

The best way to measure the angle of the knee includes three activities [11], [13]:

1. The participant should be placed in the supine position (lying on the back)
2. The knee should be extended and the hip placed in zero degrees of extension, adduction and abduction motion.
3. The knee can be flexed. The hip also flexes with the knee; see Figure 15.

![Goniometer Alignment for Measurement of Knee Flexion](image)

Figure 15. Goniometer Alignment for Measurement of Knee Flexion
To correctly align the goniometer, it should be positioned over the lateral
epicondyle of the femur with the proximal arm pointing towards the Greater
Trochanter and the distal arm pointing toward the lateral malleolus [11],[13].
Figures 15 and 16 illustrate proper alignment of the goniometer for measurement
of knee flexion and extension respectively.

Figure 16: Goniometer Alignment for Measurement of Knee Extension

2.3 Biomechanics of the Hip

This subsection studies the anatomy and range of motion of the hip joint.
Evaluation of the range of motion of the hip joint is also included.

2.3.1 Anatomy of the Hip

The hip joint is a synovial ball-and-socket joint located between the head of the
femur and the acetabulum of the pelvis [13]; see Figure 17. The hip joint is one
of the largest and most stable joints of the body that connects the inferior,
(lower), extremities with the trunk.
Nordin and Frankel document states that [12]:

“The head of the femur is the convex component of the ball-and-socket configuration of the hip joint and forms two thirds of a sphere”.

![Figure 17: Hip Joint [25]](image)

During regular activities the hip joint helps to sustain and transmit the weight of the person from the trunk to the lower extremity. Additionally, the hip joint has a large range of mobility [12].

### 2.3.2 Range of Motion of the Hip Joint

The range of motion of the hip joint is described in three planes [12], [13]:

1. Sagittal plane: The movements are flexion and extension. The motion is greater with flexion, which is from zero to approximately 140 degrees. Extension ranges from zero to approximately fifteen degrees; see Figure 18 A.
2. Frontal plane: The movements in this plane are abduction-adduction. Abduction ranges from zero to thirty degrees and adduction ranges from zero to approximately twenty-five degrees; see Figure 18 B and C.

3. Transversal plane: These motions are the internal and external rotation. External rotation ranges from zero to ninety degrees and internal rotation ranges from zero to approximately seventy degrees; see Figure 18 D and E.

![Figure 18: Movements of the Hip Joint](image)

Table 3 illustrates the range of motion of the hip for various activities.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Plane of Motion</th>
<th>Max Range Required (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking on level surfaces</td>
<td>Flexion</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Extension</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Abduction</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Adduction</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Medial Rotation</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Lateral Rotation</td>
<td>5</td>
</tr>
<tr>
<td>Ascending Stairs</td>
<td>Flexion</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Extension</td>
<td>5</td>
</tr>
<tr>
<td>Descending Stairs</td>
<td>Flexion</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>Extension</td>
<td>5</td>
</tr>
<tr>
<td>Sitting</td>
<td>Flexion</td>
<td>90</td>
</tr>
<tr>
<td>Tying shoes laces</td>
<td>Flexion</td>
<td>50</td>
</tr>
</tbody>
</table>
Table 3 shows that a person walking on a level surface produces a maximum range of flexion for the hip joint of 30 degrees, extension of 10 degrees and abduction/adduction of approximately five degrees. A person ascending or descending stairs produces an equal and opposite range of flexion and extension of 65 degrees and 5 degrees respectively. When a person sits down, the maximum range of flexion is 90 degrees. Additionally, the maximum range of flexion when a person ties their shoe laces is about 50 degrees.

2.3.3 Evaluation of the Range of Motion of the Hip

This sub-subsection explains the proper procedures to correctly measure the flexion/extension and abduction/adduction in the hip joint. A description of how to align the goniometer is included.

2.3.3.1 Flexion of the Hip

The testing procedure required to acquire flexion measurements of the hip consists of three actions [11], [13]:

1. The participant should be placed in the supine position (lying on the back).

2. The hip is placed in zero degrees of adduction/abduction and rotation motions

3. The hip is flexed. The knee also flexes with the hip; see Figure 19.
Correct alignment of the goniometer for flexion measurement requires three steps [11]:

1. Center the fulcrum of the goniometer over the lateral aspect of the hip joint using the Greater Trochanter of the femur for reference
2. Align the proximal arm with the lateral midline of the pelvis
3. Align the distal arm with the lateral midline of the femur using the lateral epicondyle for reference; see Figures 20 A and B.

Figure 19: Hip Flexion

Figure 20: Alignment of the Goniometer for Hip Joint Angle Measurement
2.3.3.2 Extension of the Hip

The testing procedure to acquire extension measurements of the hip joint requires three actions [11], [13]:

1. The participant should be placed in the prone position (lying face downward)
2. The hip is placed in zero degrees of adduction/abduction and rotation with the knee fully extended
3. The hip is extended; see Figure 21.

![Figure 21: Hip Extension](image)

Correct alignment of the goniometer for extension measurement requires three steps [11]:

1. The center of the goniometer is placed over the lateral aspect of the hip joint using the Greater Trochanter of the femur for reference.
2. Align the proximal arm with the lateral midline of the pelvis
3. Align the distal arm with the lateral midline of the femur using the lateral epicondyle for reference, see Figure 20 A.
2.3.3.3 Abduction of the Hip

The testing procedure to acquire abduction measurements of the hip joint requires three actions [11], [13]:

1. The participant is placed in the supine position (lying on the back)
2. The hip is placed in zero degrees of flexion/extension and rotation motions with the knee fully extended
3. The hip is abducted; see Figure 22.

![Figure 22: Hip Abduction](image)

Correct alignment of the goniometer for abduction measurement requires three steps [11]:

1. The center of the goniometer should be positioned over the anterior superior iliac spine, (ASIS), of the extremity being measured
2. Align the proximal arm with an imaginary horizontal line extending from one ASIS to the other ASIS
3. Align the distal arm with the anterior midline of the femur using the midline of the patella for reference; see Figure 23 A and B.
2.3.3.4 Adduction of the Hip

The correct procedure to measure the adduction of the hip joint requires three actions [11], [13]:

1. The participant is placed in the supine position (lying on the back)
2. The hip is placed in zero degrees of flexion/extension and rotation with the knee fully extended
3. The hip is adducted; see Figure 24.

The alignment of the goniometer for adduction measurement is the same as for the abduction movement; see Figure 23.
2.4 Biomechanics of the Elbow

This subsection studies the anatomy and range of motion of the elbow joint. Evaluation of the range of motion of the elbow joint is included.

2.4.1 Anatomy of the Elbow

The elbow is the middle joint of the superior extremity that links the humerus with the forearm [12], [13].

Nordin and Frankel state that [12]:

“The bony structures of the elbow are the distal end of the humerus and the proximal ends of the radius and ulna. The distal end of the humerus is formed by the hyperboloid trochlea medially and the convex capitellum laterally”.

Figure 25 presents an illustration of the elbow joint.
There are three synovial articulations that integrate the elbow joint; refer to Figure 25. The three articulations occur at [12]:

1. The humeroulnar joint, which is the articulation between the trochlea of the distal humerus and the shaped trochlear fossa of the ulna
2. The humeroradial joint, which is composed by the articulation between the capitellum of the distal humerus and the head of the radius
3. The proximal radioulnar joint, which is composed by the head of the radius and the radial notch of the proximal ulna.

In the anatomic position of the arm the large axes of the humerus and the forearm form an acute angle at the elbow that is called the "carrying angle". The measurement of the carrying angle is approximately five degrees in men and ten to fifteen degrees in women [11], [12].
2.4.2 Range of Motion of the Elbow

The range of motion of the elbow joint is limited to flexion and extension in the sagittal plane around the transverse axis [11], [13]. The elbow joint possesses two degrees of freedom [12]. The humeroulnar and humeroradial articulations permit flexion and extension motions of the elbow. In addition, the proximal radioulnar articulation permits the forearm the movements of pronation and supination. Table 4 presents an example of the different ROMs of the elbow in diverse activities.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Max Range of Flexion Required (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eating/drinking</td>
<td>130</td>
</tr>
<tr>
<td>Opening door</td>
<td>60</td>
</tr>
<tr>
<td>Reading</td>
<td>105</td>
</tr>
<tr>
<td>Using Telephone</td>
<td>135</td>
</tr>
<tr>
<td>Rising from chair</td>
<td>95</td>
</tr>
<tr>
<td>Pouring from jug</td>
<td>60</td>
</tr>
</tbody>
</table>

For example, Table 4 illustrates that the maximum range of flexion that the elbow executes during eating or drinking is approximately 130 degrees. In the case of reading a book or using the phone, the elbow is flexed approximately 105 degrees and 135 degrees, respectively.

2.4.3 Evaluation of Range of Motion of the Elbow

This sub-subsection explains the procedure required to correctly measure the flexion/extension of the elbow joint. A procedure for alignment of the goniometer is also included.
2.4.3.1 Flexion and Extension of the Elbow

The correct procedure for measurement of the flexion and extension of the elbow joint requires four actions [11], [13]:

1. The participant is placed in the supine position (lying on the back)
2. The shoulder in zero degrees of flexion/extension and abduction/adduction
3. The forearm is oriented with the palm facing upwards
4. Firm the distal end of the humerus and flex or extend the elbow as desired; see Figures 26 and 27 for details.

Figure 26: Elbow Flexion

Figure 27: Elbow Extension
Correct alignment of the goniometer for elbow joint angle measurement requires three steps [11]:

1. Place the center of the goniometer over the lateral epicondyle of the humerus

2. Align the proximal arm with the lateral midline of the humerus. Use the center of the acromial process for reference

3. Align the distal arm with the lateral midline of the radius. Use the radial head and radial styloid process for reference; see Figure 28.

Figure 28: Alignment of the Goniometer for Elbow Joint Angle Measurement
CHAPTER 3

DESCRIPTION OF HARDWARE AND SENSORS

3.1 Hardware
This subsection includes the theory and background related to the hardware utilized during this research. A description of their characteristics is also included.

3.1.1 Multifunction DAQ NI PCI-6052E
The PCI-6052E is a data acquisition, (DAQ), board made by National Instruments. The PCI-6052E is a multifunction analog, digital and timing I/O board for PCI bus computers. The PCI-6052E utilizes E Series technology to bring high-performance and reliable data acquisition capabilities in order to meet application requirements [14]; see Figure 29.

Figure 29: National Instruments PCI-6052E Board [14]
Figure 30 presents a block diagram for the PCI-6052E. The characteristics of the PCI-6052E board are:

1. Rates up to 333 kS/s
2. Resolution of 16-bits for 16 singled-ended analog inputs.
3. Analog and digital triggering capability
4. Two 24-bit, 20 MHz counter/timers
5. Eight, (8), digital I/O lines
6. Two 16-bit analog outputs.

Figure 30: PCI-6052E Block Diagram [14]
The I/O connector pin assignment for the PCI-6052E is presented in Figure 31.

![Figure 31: I/O Connector Pin Assignment](image)

<table>
<thead>
<tr>
<th>Pin Name</th>
<th>Pin Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACH8</td>
<td>34</td>
</tr>
<tr>
<td>ACH1</td>
<td>33</td>
</tr>
<tr>
<td>AIGND</td>
<td>32</td>
</tr>
<tr>
<td>ACH10</td>
<td>31</td>
</tr>
<tr>
<td>ACH3</td>
<td>30</td>
</tr>
<tr>
<td>AIGND</td>
<td>29</td>
</tr>
<tr>
<td>ACH4</td>
<td>28</td>
</tr>
<tr>
<td>AIGND</td>
<td>27</td>
</tr>
<tr>
<td>ACH13</td>
<td>26</td>
</tr>
<tr>
<td>ACH6</td>
<td>25</td>
</tr>
<tr>
<td>AIGND</td>
<td>24</td>
</tr>
<tr>
<td>ACH15</td>
<td>23</td>
</tr>
<tr>
<td>DAC0OUT</td>
<td>22</td>
</tr>
<tr>
<td>DAC1OUT</td>
<td>21</td>
</tr>
<tr>
<td>EXTRREF</td>
<td>20</td>
</tr>
<tr>
<td>DIO4</td>
<td>19</td>
</tr>
<tr>
<td>DGND</td>
<td>18</td>
</tr>
<tr>
<td>DIO1</td>
<td>17</td>
</tr>
<tr>
<td>DGND</td>
<td>16</td>
</tr>
<tr>
<td>DIO6</td>
<td>15</td>
</tr>
<tr>
<td>DGND</td>
<td>14</td>
</tr>
<tr>
<td>DGND</td>
<td>13</td>
</tr>
<tr>
<td>DGND</td>
<td>12</td>
</tr>
<tr>
<td>DGND</td>
<td>9</td>
</tr>
<tr>
<td>DGND</td>
<td>8</td>
</tr>
<tr>
<td>DGND</td>
<td>7</td>
</tr>
<tr>
<td>PFI0/TRIG1</td>
<td>11</td>
</tr>
<tr>
<td>PFI1/TRIG2</td>
<td>10</td>
</tr>
<tr>
<td>PFI2/CONVERT*</td>
<td>9</td>
</tr>
<tr>
<td>PFI3/GPCTR1_SOURCE</td>
<td>8</td>
</tr>
<tr>
<td>PFI4/GPCTR1_GATE</td>
<td>7</td>
</tr>
<tr>
<td>GPCTR1_OUT</td>
<td>6</td>
</tr>
<tr>
<td>DGND</td>
<td>5</td>
</tr>
<tr>
<td>DGND</td>
<td>4</td>
</tr>
<tr>
<td>PFI9/GPCTR0_GATE</td>
<td>3</td>
</tr>
<tr>
<td>GPCTR0_OUT</td>
<td>2</td>
</tr>
<tr>
<td>DGND</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 31: I/O Connector Pin Assignment
The PCI-6052E is able to interface with an SCXI system so that it can simultaneously acquire over 3,000 analog signals from thermocouples, RTDs, strain gauges, voltage sources and current sources. The PCI-6052E can also acquire or generate digital signals for communication and control. The SCXI system was used as the instrumentation front end for plug-in DAQ boards [14].

3.1.2 The NI SCXI-1000 Chassis

The NI SCXI-1000 is a 4-slot chassis with a number of standard AC power options. This chassis is ideal for low-channel count applications. The NI SCXI-1000 chassis is a low noise chassis that houses, power, SCXI control modules and conditioned signals. The NI SCXI-1000 architecture includes the SCXI-bus, which routes analog and digital signals and operates as the communication device between modules. The SCXI-bus acts as a conduit for signal routing, transferring data, programming modules and passing timing signals. Chassis control circuitry manages the bus by synchronizing the timing between each module and the DAQ device. The NI SCXI-1000 can scan input channels from several modules in several chassis at rates up to 333 kS/s for every DAQ device [15]; see Figure 32.

The main characteristics of the SCXI-1000 chassis are:

1. Rugged and compact 4-slot AC-powered chassis houses any SCXI module
2. Low-noise signal conditioning environment
3. Three internal analog buses
4. Timing circuitry for high-speed multiplexing
5. NI-DAQ driver simplifies configuration and measurements
6. Shielded enclosures for SCXI modules
7. Rugged, compact chassis
8. Forced air-cooling
9. Optional rack mounting

Figure 32: NI SCXI-1000 Chassis [15]

3.1.3 The NI SCXI-1300 Terminal Block

The SCXI-1300 connects input signals to the SCXI-1100 module. The SCXI-1300 is a general-purpose terminal block with an onboard temperature sensor for cold-junction compensation. SCXI terminal blocks provide a convenient method for connecting and disconnecting signals to the system. The SCXI-1300 front-mount terminal block supplies direct connections to transducers at the screw terminals located within a fully shielded enclosure or at front-mounted BNC connectors. Strain-relief clamps hold the signal wires safely in place [16]; see Figure 33.
The characteristics of the SCXI-1300 terminal block are [16]:

1. Quick and easy connections
2. Strain-relief clamps for reliable wiring
3. Connectivity options including BNC and thermocouple plugs
4. Shielded front-mount terminal blocks
5. Onboard temperature sensor for cold-junction compensation

Terminal blocks are ideal solutions for large-channel-count temperature or voltage applications. Figure 34 presents the interconnection between the NI SCXI-1000 chassis, the SCXI-1300 terminal block and the computer.
3.2 Sensors

This subsection includes the theory and background related to the sensors utilized during this research. A description of their characteristics is also included.

3.2.1 Flex Sensor

This subsection provides a description of the Flex sensor. Its basic circuit characteristics are also included.

3.2.1.1 Description

The flex sensor is a component that changes its resistance when bent. This sensor has a nominal resistance when it is at rest or unbent. As the Flex Sensor is bent the resistance gradually increases. For example, if a sensor produces 10,000 ohms, (10 Kohms), at rest, its resistance will range between 25-40 Kohms when it is bent to 90 degrees [17]. Figure 35 illustrates a standard flex sensor.

3.2.1.2 Basic Circuit of the Flex Sensor

Flex sensors use the basic circuit presented in Figure 36. The circuit uses a general-proposal operational amplifier, LM741CN, to amplify the signal from the sensor. The input voltage, Vin, is 5 volts and the resistors R1 and R2 are equal to the resistance of the sensor and 20 Kohms respectively. Vout is the output voltage that will be received by the data acquisition device and sent to the computer [18].
Figure 35: Flex Sensor [17]

Figure 36: Basic Circuit for the Flex Sensor [10]
3.2.2 Electrogoniometer

This subsection provides a description of the electrogoniometers. Its basic circuit characteristics are also included.

3.2.2.1 Description

Electrogoniometers are devices capable of transforming angular position into a proportional electrical signal. Electrogoniometers include gauge elements that measure bending strain along or around a particular axis. The bending strain is proportional to the sum total of the angular shift along an axis. The output signal is a function that is proportional to the angular movement. Electrogoniometers are designed for the measurement of limb angular movement [22]. Figure 37 presents a detailed illustration of an electrogoniometer.

![Illustration of the Electrogoniometer](image)

Figure 37: Illustration of the Electrogoniometer

Where

1. A Max: 150 mm
2. A Min: 130 mm
3. B: 70 mm
4. C: 18 mm
5. D: 54 mm
6. E:  20 mm
7. Weight:  19g

The characteristics of the sensor can be summarized as follow:

1. Transducer type:  Strain gauge
2. Life:  600,000 cycles typical
3. Accuracy:  ± 2º measured over a range of ± 90º
4. Repeatability:  1º measured over a range of 90º
5. Operating temperature range:  +10ºC to +40ºC
6. Temperature zero drift:  ≤ 0.15 degrees angle / ºC
7. Number of Channels:  2

The sensor used for this study was the SG150 twin axis electrogoniometer, which was built by Biometrics. The SG150 twin axis electrogoniometer can simultaneously measure angles in two planes of movement. For example, flexion/extension and abduction/adduction deviation can be measured simultaneously. The SG150 twin axis electrogoniometer possesses a separate output connector for each of the movements [23]. Figure 38 presents an example of twin axes electrogoniometers.

Figure 38: Electrogoniometers [23]
Electrogoniometers are unobtrusive, lightweight and can be attached to the body surface using double sided surgical tape and can be further secured with single sided tape. Electrogoniometers have a telescopic end block that compensates for changes in distance between the two mounting points as the limb moves [22]. The various parts of an electrogoniometer are illustrated in Figure 39.

![Figure 39: Parts of the Electrogoniometer [22]](image)

### 3.2.2.2 Basic Circuit for the Electrogoniometer

The basic circuit associated with an electrogoniometer is a differential amplifier; see Figure 40. This circuit amplifies the difference between its two input terminals.
Figure 40: Basic Circuit for the Electrogoniometer

The differential amplifier presented in Figure 40 requires that

\[ R_1 = R_4 \]

and

\[ R_2 = R_3. \]

The output voltage is determined from the equation

\[ V_{\text{out}} = \left( \frac{R_2}{R_1} \right) \times (V_{\text{in}2} - V_{\text{in}1}). \]

Each channel of the electrogoniometer is a Wheatstone bridge arrangement; see Figure 41.

Figure 41: Wheatstone Bridge
The specifications of the Wheatstone bridge are:

1. Power supply to the bridge is from one to five voltages
2. Sensitivity: 10 milli-volt / degree angle / supply voltage.

Wiring details for the four colored interconnecting cables of the electrogoniometer are:

1. Red: +ve supply voltage
2. Green: Ground
3. Yellow: +ve output voltage
4. Blue: Output ground

$V_{in1}$ is the output ground (blue cable); and $V_{in2}$ is the +ve output voltage (yellow cable).

### 3.2.3 Photocell

This subsection provides a description of the photocells that were utilized to measure skin pressure distribution. Its basic circuit and characteristics are also included.

#### 3.2.3.1 Description

A photocell is a type of resistor whose resistance value is proportional to incident light. When not exposed to light the resistance of the photocell is maximum. When the photocell is exposed to light its resistance decreases in a manner proportional to the exposure level. Photocells can be used to detect large or small fluctuations in light levels to differentiate between one light bulb or two,
direct sunlight or total darkness and anything in between. Figure 42 presents an example of the changes in resistance of the photocell [19].

![Figure 42: Photocell Concept Diagram [19]](image)

### 3.2.3.2 Basic Circuit for the Photocell

The circuit for the photocell is a basic voltage divider. This circuit is employed because it is necessary to get a voltage to the device. The purpose of the voltage divider is to provide a counterbalance to the resistance the photocell will provide in the desired light conditions [16]. Figure 43 presents the details of a voltage divider circuit for a photocell.

![Figure 43: Basic Circuit Photocell [19]](image)
When light impinges on the photocell its resistance reduces and the voltage at Ain increases towards five Volts. If light does not impinge on the photocell its resistance increases and the voltage at Ain decreases towards zero volts. To select the proper resistance, “r”, in the voltage divider, the photocell is positioned in the place where it is going to be used with room light. An ohmmeter is utilized to measure the resistance of the photocell. The value measured, or a little higher, is the recommended value for “r”.

3.2.4 Brake Pad Sensor

This subsection provides a description of the Brake Pad Sensor. Its basic circuit and characteristics are also included.

3.2.4.1 Description

A ‘Brake Pad Sensor’ utilizes matrix pressure sensing technology [20]. Each pressure measurement system is a thin, ~0.1 mm, flexible tactile force sensor. Sensors come in both grid-based and single load cell configurations. These sensors are capable of measuring pressures ranging from 0-15 KN/m² to 0-175 MN/m². Sensing locations within the matrix can be as small as .0009 square inches, (.140 mm²),. Therefore, a one square centimeter area can contain an array of 170 sensors [20]; see Figure 44. The brake pad sensor can be trimmed as a function of the requirements or special needs of the location where the sensor will be placed.
3.2.4.2 Basic Circuit for the Brake Pad Sensor

The basic circuit utilized with the brake pad sensor is presented in Figure 45. The circuit has an operational amplifier, LM741CN, to amplify the output signal. The sensor is powered with -5 volts. The resistance value is 33 Kohms or 47 Kohms depending of the place where the sensor is to be utilized. Vout is the output voltage. The typical sensor response between force in pounds and the output voltage is illustrated in Figure 46.
Figure 46: Typical Sensor Response [20]
4.1 Overview

The design of instrumented mannequin was implemented using National Instruments LabView software [24], which was able to provide both spasm simulation process control and a history of the acquired sensor data. A virtual instrument (VI) was developed using LabView™ as the interface between the user or instructor and the instrumented mannequin. This VI has the capability to show the history of the acquired data so the trainer is able to analyze the sensors information and verify the procedural accuracy of the tasks performed on the simulated patient by the student. Figure 47 shows illustrate the integrated system.

Figure 47: Integrated Mannequin System
4.2 Joint Angle Measurements

This subsection will describe in detail the method used to install each one of the sensors on the mannequin used to measure the joint angles. A description of the technique utilized to acquire the data in this study is also provided.

4.2.1 Knee Angle Measurement

To install the flex sensor on the knee joint, the mannequin was lying on its back with its right leg straight. The sensor was aligned in the center of the knee joint. A plastic tube was used as a guide or channel for the flex sensor to run back and forth when the knee joint was flexed. The plastic tube was attached on the mannequin with a regular adhesive tape; see Figure 48. The cable coming from the sensor to the circuit was run inside the body of the mannequin.

![Figure 48: Installation of the Flex Sensor on the Knee Joint](image)

To acquire angle measurements for the knee joint, the procedures presented in chapter 2 for performing flexion and extension motions and aligning the goniometer were followed; see figure 49. Measurements were taken three times
and then averaged. Table 5 shows the measurements recorded for the knee joint. Angle measures were recorded up to 100 degrees flexion due to restriction of movement for the mannequin knee joint.

![Figure 49: Angle Measurement Knee Joint](image)

<table>
<thead>
<tr>
<th>Angle</th>
<th>Volt1</th>
<th>Volt2</th>
<th>Volt3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.79</td>
<td>1.8</td>
<td>1.79</td>
<td>1.79</td>
</tr>
<tr>
<td>10</td>
<td>1.77</td>
<td>1.78</td>
<td>1.74</td>
<td>1.76</td>
</tr>
<tr>
<td>20</td>
<td>1.67</td>
<td>1.67</td>
<td>1.67</td>
<td>1.67</td>
</tr>
<tr>
<td>30</td>
<td>1.54</td>
<td>1.59</td>
<td>1.53</td>
<td>1.55</td>
</tr>
<tr>
<td>40</td>
<td>1.47</td>
<td>1.5</td>
<td>1.48</td>
<td>1.48</td>
</tr>
<tr>
<td>50</td>
<td>1.37</td>
<td>1.38</td>
<td>1.38</td>
<td>1.38</td>
</tr>
<tr>
<td>60</td>
<td>1.28</td>
<td>1.27</td>
<td>1.3</td>
<td>1.28</td>
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<tr>
<td>70</td>
<td>1.24</td>
<td>1.25</td>
<td>1.25</td>
<td>1.25</td>
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<tr>
<td>80</td>
<td>1.21</td>
<td>1.22</td>
<td>1.24</td>
<td>1.22</td>
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<tr>
<td>90</td>
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<tr>
<td>100</td>
<td>1.2</td>
<td>1.2</td>
<td>1.21</td>
<td>1.20</td>
</tr>
</tbody>
</table>

It can be observed from Table 5 that the three voltage values from the flex sensor are very similar, indicating a high level of sensor reliability. These values were graphed in Excel and are presented in Figure 50.
It can be observed from Figure 50 that relation between angle and voltage is linear. The equation defining voltage average relationship was used for the interpolation of the angle in LabView™.

**4.2.2 Hip Angle Measurement**

The electrogoniometer was mounted across the hip joint. The fixed endblock was attached to the side of the trunk in the pelvic region as shown in Figures 51A and Figure 51B. With the limb in the position of reference, the electrogoniometer was extended to maximum length. The telescopic endblock was attached to the thigh so that the axis of the thigh and endblock coincide, when viewed in the sagittal plane. Double-sided adhesive tape was employed between the endblocks and the mannequin’s skin, and single sided adhesive tape was placed over the top of the endblocks. No tape should come into contact with the spring [23]. The thigh may now be flexed or extended, abducted or adducted, see
figure 52. Measurements of flexion/extension were obtained from the green marked plug; abduction/adduction from the grey plug. The cable coming from the sensor to the circuit was run inside the body of the mannequin.

Figure 51: Installation of the Electrogoniometer Across the Hip Joint

Figure 52: Flexion of the Hip Joint

It was necessary to modify the mannequin hip joint to permit more freedom of movement of this joint; see Figure 53. Note that marks were made on the mannequin. These marks indicate limits of motion of the electrogoniometer to prevent damage of the sensor.
To acquire angle measurements for the hip joint, the directions presented in chapter 2 for performing flexion/extension and abduction/adduction motions were followed; as well for aligning the electrogoniometer. The measurements were taken three times and then averaged. Table 6 shows the measurements taken for the hip joint flexion/extension motions. The flexion angle measure was recorded up to 70 degrees and the extension angle measure was only recorded up to 30 degrees due to the restriction of the mannequin hip joint.

Table 6: Angle-Voltage Data for Hip Joint Flexion/Extension

<table>
<thead>
<tr>
<th>Angle</th>
<th>Volt1</th>
<th>Volt2</th>
<th>Volt3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>-30</td>
<td>1.91</td>
<td>1.9</td>
<td>1.91</td>
<td>1.91</td>
</tr>
<tr>
<td>-20</td>
<td>1.84</td>
<td>1.85</td>
<td>1.83</td>
<td>1.84</td>
</tr>
<tr>
<td>-10</td>
<td>1.8</td>
<td>1.81</td>
<td>1.8</td>
<td>1.80</td>
</tr>
<tr>
<td>0</td>
<td>1.72</td>
<td>1.71</td>
<td>1.72</td>
<td>1.72</td>
</tr>
<tr>
<td>10</td>
<td>1.68</td>
<td>1.67</td>
<td>1.67</td>
<td>1.67</td>
</tr>
<tr>
<td>20</td>
<td>1.59</td>
<td>1.56</td>
<td>1.54</td>
<td>1.56</td>
</tr>
<tr>
<td>30</td>
<td>1.48</td>
<td>1.49</td>
<td>1.49</td>
<td>1.49</td>
</tr>
<tr>
<td>40</td>
<td>1.4</td>
<td>1.4</td>
<td>1.39</td>
<td>1.40</td>
</tr>
<tr>
<td>50</td>
<td>1.35</td>
<td>1.36</td>
<td>1.35</td>
<td>1.35</td>
</tr>
<tr>
<td>60</td>
<td>1.26</td>
<td>1.29</td>
<td>1.28</td>
<td>1.28</td>
</tr>
<tr>
<td>70</td>
<td>1.22</td>
<td>1.21</td>
<td>1.2</td>
<td>1.21</td>
</tr>
</tbody>
</table>

*The negative sign of the angle value indicates extension motion.

Table 7 presents the measurements taken for the hip joint abduction/adduction motions. The abduction angle measure was recorded up to 35 degrees and the
adduction angle measure was only recorded up to 7 degrees due to the restriction of the mannequin hip joint.

Table 7: Angle-Voltage Data for Hip Joint Abduction/Adduction

<table>
<thead>
<tr>
<th>Angle</th>
<th>Volt1</th>
<th>Volt2</th>
<th>Volt3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>-7*</td>
<td>1.21</td>
<td>1.2</td>
<td>1.22</td>
<td>1.21</td>
</tr>
<tr>
<td>0</td>
<td>1.28</td>
<td>1.26</td>
<td>1.28</td>
<td>1.27</td>
</tr>
<tr>
<td>5</td>
<td>1.32</td>
<td>1.29</td>
<td>1.31</td>
<td>1.31</td>
</tr>
<tr>
<td>10</td>
<td>1.36</td>
<td>1.32</td>
<td>1.34</td>
<td>1.34</td>
</tr>
<tr>
<td>15</td>
<td>1.41</td>
<td>1.39</td>
<td>1.4</td>
<td>1.40</td>
</tr>
<tr>
<td>20</td>
<td>1.46</td>
<td>1.43</td>
<td>1.44</td>
<td>1.44</td>
</tr>
<tr>
<td>25</td>
<td>1.51</td>
<td>1.5</td>
<td>1.5</td>
<td>1.50</td>
</tr>
<tr>
<td>30</td>
<td>1.53</td>
<td>1.54</td>
<td>1.55</td>
<td>1.54</td>
</tr>
<tr>
<td>35</td>
<td>1.57</td>
<td>1.56</td>
<td>1.58</td>
<td>1.57</td>
</tr>
</tbody>
</table>

*The negative sign of the angle value indicates adduction motion.

It can be observed from Tables 6 and 7 that the three voltages values from the sensor are very similar, indicating a high level of sensor reliability and measurement repeatability. These values were graphed in Excel; see Figure 54 and 55.

Figure 54: Angle-Voltage Data for the Hip Joint Flexion/Extension
Figures 54 and 55 illustrate that the relation between angle and voltage is almost linear. The equation defining voltage average relationship was used for interpolation of the angle values in LabView™.

### 4.2.3 Elbow Angle Measurement

A flex sensor it was installed across the elbow joint. A plastic tube was used as a guide or channel for the flex sensor to run back and forth when the elbow joint was flexed. The plastic tube was attached on the mannequin with regular adhesive tape; see Figure 56. The cable coming from the sensor to the circuit was run inside the body of the mannequin.

To acquire angle measurements for the elbow joint, the directions presented in chapter 2 for performing flexion and extension motions were followed; see Figure 57. The measurements were taken three times and then averaged. Table 8
presents the measurements taken for the elbow joint. The angle measure was recorded up to 90 degrees due to restriction of the mannequin elbow joint.

![Figure 56: Installation of the Flex Sensor of the Elbow Joint](image)

![Figure 57: Angle Measurement Elbow Joint](image)

**Table 8: Angle-Voltage Data for the Elbow Joint**

<table>
<thead>
<tr>
<th>Angle</th>
<th>Volt1</th>
<th>Volt2</th>
<th>Volt3</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.41</td>
<td>1.41</td>
<td>1.41</td>
<td>1.41</td>
</tr>
<tr>
<td>10</td>
<td>1.37</td>
<td>1.37</td>
<td>1.37</td>
<td>1.37</td>
</tr>
<tr>
<td>20</td>
<td>1.31</td>
<td>1.3</td>
<td>1.31</td>
<td>1.31</td>
</tr>
<tr>
<td>30</td>
<td>1.24</td>
<td>1.24</td>
<td>1.24</td>
<td>1.24</td>
</tr>
<tr>
<td>40</td>
<td>1.19</td>
<td>1.18</td>
<td>1.19</td>
<td>1.19</td>
</tr>
<tr>
<td>50</td>
<td>1.14</td>
<td>1.14</td>
<td>1.14</td>
<td>1.14</td>
</tr>
<tr>
<td>60</td>
<td>1.08</td>
<td>1.08</td>
<td>1.09</td>
<td>1.08</td>
</tr>
<tr>
<td>70</td>
<td>1.04</td>
<td>1.04</td>
<td>1.04</td>
<td>1.04</td>
</tr>
<tr>
<td>80</td>
<td>0.99</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>90</td>
<td>0.97</td>
<td>0.98</td>
<td>0.97</td>
<td>0.97</td>
</tr>
</tbody>
</table>
According to Table 8 the three voltages values from the elbow flex sensor are very similar, indicating a highly reliable sensor. The average values were graphed in Excel and are presented in Figure 58.

![Angle-Voltage Data for Elbow Joint](image)

Figure 58: Angle-Voltage Data for the Elbow Joint

Figure 58 illustrates that relation between angle and voltage is linear. The equation defining voltage average was used for interpolation of the angle value in LabView™.

### 4.3 Undignified Exposure Measurement

To study the dignity of the patient, photocells were installed on the mannequin’s body. The areas of the mannequin selected were the nipples, the genital area and the buttocks. Two sensors were placed on the chest, one on the right side and another one on the left side. One sensor was placed on the genital area, and the last sensor on the buttocks area. Figure 59 illustrates the locations of the photocells on the chest.
Figure 59: Installation of Photocell on the Chest

The characteristics of each of the photocells are summarized as follow:

1. Right side chest: Photocell characteristics are presented in Table 9.

   Table 9: Photocell Characteristics Right Chest

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Resistance (ohms)</th>
<th>Voltage (volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>420</td>
<td>2.56</td>
</tr>
<tr>
<td>Dark</td>
<td>772</td>
<td>1.66</td>
</tr>
</tbody>
</table>

2. Left side chest: Photocell characteristics are presented in Table 10.

   Table 10: Photocell Characteristics Left Chest

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Resistance (ohms)</th>
<th>Voltage (volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>230</td>
<td>2.68</td>
</tr>
<tr>
<td>Dark</td>
<td>423</td>
<td>1.91</td>
</tr>
</tbody>
</table>

3. Genital Area: Photocell characteristics are presented in Table 11.

   Table 11: Photocell Characteristics Genital Area

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Resistance (ohms)</th>
<th>Voltage (volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>2.3 k</td>
<td>2.3</td>
</tr>
<tr>
<td>Dark</td>
<td>3.26 k</td>
<td>1.64</td>
</tr>
</tbody>
</table>
4. Buttocks Area: Photocell characteristics are presented in Table 12.

Table 12: Photocell Characteristics Buttocks Area

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Resistance (ohms)</th>
<th>Voltage (volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>270</td>
<td>1.753</td>
</tr>
<tr>
<td>Dark</td>
<td>570</td>
<td>0.0023</td>
</tr>
</tbody>
</table>

The voltage values were used to record undignified exposure, and recorded by LabView™ VI. This procedure will be described in detail in subsection 4.5.

4.4 Skin Pressure Measurement

Two force sensing resistors, (FSR), were placed on the mannequin’s body to study the skin pressure distribution when a patient is being turned over, see figure 60. One sensor was placed on the mannequin’s left upper arm and another one on the left thigh. The sensors were covered with a plastic board to distribute more uniform the force on the FSR, see figure 61.

Figure 60: Subject Turning the Mannequin Over
The sensors were calibrated using a Chatillon force gauge (DG-1000N), see Figure 62A and Figure 62B. Measurements were taken three times and averaged. The values taken for the FSR installed on the mannequin’s arm were acquired every 50 N until 550 N, and the measurements taken for the FSR installed on the mannequin’s thigh were acquired every 20 N until 180 N. Table 13 and Table 14 show the measurements taken in each force sensing resistor.
Table 13: Angle-Voltage Data for Force Sensing Resistor Installed on the Mannequin’s Arm

<table>
<thead>
<tr>
<th>Force (N)</th>
<th>Sensor1A</th>
<th>Sensor1B</th>
<th>Sensor1C</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>0.61</td>
<td>0.58</td>
<td>0.57</td>
<td>0.59</td>
</tr>
<tr>
<td>100</td>
<td>1.09</td>
<td>0.95</td>
<td>1.01</td>
<td>1.02</td>
</tr>
<tr>
<td>150</td>
<td>1.62</td>
<td>1.5</td>
<td>1.44</td>
<td>1.52</td>
</tr>
<tr>
<td>200</td>
<td>2.08</td>
<td>1.96</td>
<td>2.06</td>
<td>2.03</td>
</tr>
<tr>
<td>250</td>
<td>2.45</td>
<td>2.23</td>
<td>2.39</td>
<td>2.36</td>
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<tr>
<td>300</td>
<td>2.94</td>
<td>2.35</td>
<td>2.77</td>
<td>2.69</td>
</tr>
<tr>
<td>350</td>
<td>3.36</td>
<td>2.85</td>
<td>3.15</td>
<td>3.12</td>
</tr>
<tr>
<td>400</td>
<td>3.57</td>
<td>3.22</td>
<td>3.37</td>
<td>3.39</td>
</tr>
<tr>
<td>450</td>
<td>3.79</td>
<td>3.49</td>
<td>3.55</td>
<td>3.61</td>
</tr>
<tr>
<td>500</td>
<td>4.16</td>
<td>4.06</td>
<td>4.09</td>
<td>4.10</td>
</tr>
<tr>
<td>550</td>
<td>4.39</td>
<td>4.22</td>
<td>4.47</td>
<td>4.36</td>
</tr>
</tbody>
</table>

Table 13 presents the angle-voltage average for the sensor located on the mannequin’s arm. The three voltages values recorded for the sensor is very similar, indicating a high level of sensor reliability and measurement repeatability. The average value was graphed in Excel and presented in Figure 63.

![Figure 63: Force-Voltage Calibration for Force Sensing Resistor Located on Mannequin’s Arm](image-url)
Table 14: Angle-Voltage Data for Force Sensing Resistor Installed on the Mannequin’s Thigh

<table>
<thead>
<tr>
<th>Force (N)</th>
<th>Sensor2A</th>
<th>Sensor2B</th>
<th>Sensor2C</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>20</td>
<td>0.66</td>
<td>0.61</td>
<td>0.72</td>
<td>0.66</td>
</tr>
<tr>
<td>40</td>
<td>1.15</td>
<td>1.03</td>
<td>1.14</td>
<td>1.11</td>
</tr>
<tr>
<td>60</td>
<td>1.62</td>
<td>1.56</td>
<td>1.59</td>
<td>1.59</td>
</tr>
<tr>
<td>80</td>
<td>1.98</td>
<td>1.84</td>
<td>1.96</td>
<td>1.93</td>
</tr>
<tr>
<td>100</td>
<td>2.38</td>
<td>2.23</td>
<td>2.24</td>
<td>2.28</td>
</tr>
<tr>
<td>120</td>
<td>2.61</td>
<td>2.85</td>
<td>2.55</td>
<td>2.67</td>
</tr>
<tr>
<td>140</td>
<td>3.21</td>
<td>3.41</td>
<td>3.32</td>
<td>3.31</td>
</tr>
<tr>
<td>160</td>
<td>4.56</td>
<td>4.18</td>
<td>4.38</td>
<td>4.37</td>
</tr>
<tr>
<td>180</td>
<td>5.01</td>
<td>4.69</td>
<td>5.22</td>
<td>4.97</td>
</tr>
</tbody>
</table>

Table 14 presents the angle-voltage averages for the sensor located on the mannequin’s thigh. The three voltages values taken for the sensor are also very similar, indicating a high level of sensor reliability and measurement repeatability. The average value was graphed in Excel and can be seen in Figure 64. Measurements for both FSR sensors were used to interpolate the angle value in LabView™.

Figure 64: Force-Voltage Calibration for Force Sensing Resistor Located on Mannequin’s Thigh
4.5 Interface Human-Computer

A virtual instrument, (VI), was developed using LabView™ as the interface between the user or instructor and the instrumented mannequin. The VI had the capability of presenting the history of the acquired data to allow the trainer to be able to analyze the sensors information and verify the procedural accuracy of tasks performed on the simulated patient by the student. Figure 65 illustrates the workstation for the “Instrumented Mannequin”. The following subsections will describe in detail the virtual instrument (VI) created for this system.

4.5.1 Main VI LabView™ Screen

The main Labview™ VI screen was the interface between the instrumented mannequin and the user. The VI screen is presented in Figure 66.
The characteristics of the Main VI Interface Screen were:

1. “Samples” are the number of data points per channel that the VI acquires before acquisition completes; 300 data points per channel was the default solution.

2. “Samples/s” is the number of samples per second that the VI acquires. This is the sampling rate per channel; 1000 samples/sec is the default solution.

3. The three first graphs show the angle plot for the elbow, knee, and hip joints. The last graph shows the force for the skin pressure distribution on the mannequin’s arm and thigh.

4. The four LEDs are included to study the dignity of the patient. Each LED is illuminated respective of the area on the patient that is exposed or undressed.
5. The button “Save Data” is used to store the data in a .txt file to generate a report.

6. The “Stop” button suspended data collection.

4.5.2 Description of the Developed VI's using LabView™

This subsection describes the LabView™ program that was created for this system. A description for each of the designs is included.

4.5.2.1 Data Acquisition VI

The following design was used to acquire data:

![Data Acquisition Interface Design](image)

Figure 67: Data Acquisition Interface Design
“Oneida0” thru “Oneida9”, labeled above, represent the channels used on the data acquisition board. The mean value was calculated for each of the variables in study; see Figure 68.

![Figure 68: Mean Value Example Design](image)

The structure presented in Figure 68 was used to calculate the mean values for each of the joints and for the force on the arm and the thigh. The structure presented in Figure 69 was used to calculate the mean value and to create an array for all photocells.

![Figure 69: Mean Value Example Design for Photocell on the Left Chest](image)

Calibrated means were used to compute the interpolation of the data as described in the following subsection.

### 4.5.2.2 Interpolation of Values

Angle, force, and voltage values from section 4.2 were copied to the program to produce an array of the values for subsequent use in the interpolation design.
Figure 70 shows the components of this design for the elbow and hip joints. The negative angle (-0.01) shown on Figure 70A is used to check the hyperextension of the elbow. The negative values on Figure 70B indicates adduction motion of the hip joint. For example, if the Main VI Screen shows in the “Angle Ab/Ad” box the value minus seven, this means that the motion is seven degrees adduction.

After the values were compiled in an array, they were used to interpolate the angle of the joints. In the case of the force-sensing resistor, the force and voltage arrays were used to interpolate the force on the mannequin’s arm and thigh.

Figure 70: Angle and Voltage Arrays for Elbow and Hip Joints
Figure 71 presents the standard interpolation for all angle joints. This design was used to compute the interpolation values for the elbow, knee, and hip joints, as well as forces on the arm and thigh.

4.5.2.3 Plot of Data and Conditions

Once the data were interpolated, they were graphed using the LabView graph command. In addition, there were some conditions that the system had to take into consideration. The system had to alert the instructor when the student was using too much force in the motion of the elbow, knee or the hip joint. To accomplish this task a structure was designed as shown on Figure 72. For example, in the case of the elbow joint, if a student pushes too hard on the arm of the mannequin during flexion, the graph will change color and a sound will beep to alert the instructor. A similar structure was utilized for the knee and hip joints.
4.5.2.4 Export and Save Data

The VI design shown in Figure 73 was used to export the data and store it for future use. Once the instructor pushes the button “Save Data” on the Main VI Screen, a window pops up to save the data in a .txt file, see Figure 74. After the data is saved, it can be exported to Excel for further analysis. The instructor can produce a report for each of his/her students.
Figure 73: Design to Export and Save the Data

Figure 74: Pop Up Window to Save the Data
CHAPTER 5

RESULTS

5.1 Results

Once the data was acquired and saved it was exported to Microsoft’s spreadsheet program, Excel, where a report was generated. Examples of the report are presented in Table 14. The angle values obtained for the elbow, knee and hip joints were very similar to the ones measured manually using the goniometer. The force measurements for the mannequin’s arm and leg were also shown to be accurate. The zeroes and ones presented for the photocells, Left Chest, Right Chest, Genital Area, Buttocks Area, indicate that the mannequin was either dressed or not dressed. A value of one indicates that the mannequin was undressed and a value of zero indicates that the mannequin was dressed. The column labeled “Buttocks Area” recorded only zeroes because the mannequin was lying on its back.

A graph was generated for each of the variables studied on the Instrumented Mannequin. The graphs for the variables studied are presented in Figures 75, 76, 77, 78 and 79.
### Table 15: Data Report Exported to Excel

**Development of a Instrumented Mannequin for Training Caregivers**

<table>
<thead>
<tr>
<th>Measurements Result</th>
<th>Elbow</th>
<th>Knee</th>
<th>Hip Flex/Ext</th>
<th>Hip Ab/Ad</th>
<th>Force Arm</th>
<th>Force Leg</th>
<th>Left Chest</th>
<th>Right Chest</th>
<th>Genital Area</th>
<th>Buttocks Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.19</td>
<td>1.36</td>
<td>3.06</td>
<td>1.08</td>
<td>18</td>
<td>3.84</td>
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<td></td>
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<tr>
<td>2.25</td>
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<td>1.07</td>
<td>18</td>
<td>3.84</td>
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<td>0</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
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<td>0</td>
<td></td>
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</tr>
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<td>1</td>
<td>0</td>
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</tr>
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<td>6.18</td>
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<td>1.18</td>
<td>63.9</td>
<td>46.6</td>
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The graph of the values from the “Elbow Report” illustrate that the elbow was gradually flexed to approximately 70 degrees. Afterwards, the arm was extended to approximately 35 degrees and flexed again to approximately 80 degrees. The values for the “Knee Report” illustrate that the knee was flexed to approximately 5 degrees and was steady in that position for few seconds. Then the knee was gradually increased in flex to approximately 50 degrees.
The graph of the data associated with the “Left Exposure Report”, which is presented in Figure 76, indicates that the mannequin was undressed for approximately 12 seconds, dressed for 3 seconds and undressed again for
approximately 10 seconds. Studies of the graphs for the rest of the photocells produce similar results.

![Graph of Hip Flexion/Extension and Abduction/Adduction Activity](image)

**Figure 78:** Hip Flexion/Extension and Abduction/Adduction Activity

A graph of the hip data is presented in Figure 78. The graph indicates that the hip joint was flexed to approximately 15 degrees for the first 5 seconds, extended to approximately 5 degrees where it remained for approximately 15 seconds and then the hip was gradually flexed to approximately 90 degrees. The hip joint was also abducted to approximately 2 degrees.
A graph of the force application data is presented in Figure 79. Pressure was applied to the mannequin’s arm with a force between 50 and 100 Newton, which corresponds to 12 to 22 pounds. Similarly, pressure was applied to the thigh with a force between 45 and 70 Newton, which corresponds to approximately 10 to 16 pounds. The peaks on the above graph indicate that when the mannequin was turned over the pressure was released on the arm and leg and then the arm and leg were held back again.
5.2 Results: Phase II

Based on recommendations, arising from a critical design review, velocity measurements associated with joint angle motions were incorporated as an additional monitoring tool for measure of risk to the patient.

An analysis of the data was performed in order to discover if significant noise was associated with the signal data. The noise investigation was performed with the aid of Matlab software. The unfiltered angular displacement data for the elbow exhibited some noise; see Figure 80.

![Unfiltered Data for Elbow Angular Displacement](image)

**Figure 80: Unfiltered Data for Elbow Angular Displacement**

Since velocity is a derivative operation, any noise associated with the signal, whose velocity is to be calculated, will be accentuated. The derivative associated with the unfiltered elbow angular displacement data was calculated. The results, unfiltered elbow angular velocity, are presented in Figure 81.
The unfiltered angular velocity is essentially unusable due to the presence of noise in the unfiltered angular displacement data. Therefore, prior to developing a velocity profile for the data, a Fast Fourier Transform, (FFT), analysis was performed. The results of the FFT analysis are presented in Figure 82. The FFT data shows that the frequency components associated with elbow angular displacement lie in a frequency band that does not exceed ten hertz.
The velocity analysis indicated a need for filtering the data associated with elbow angular displacement and the FFT analysis uncovered the required filter range. Since a sharp cutoff for the filter was desired a fourth order Butterworth Low-pass digital filter was designed and incorporated into the Labview™ system in order to minimize the effect of the presence of noise on velocity profile data. The Labview™ panel used in the filter design is presented in Figure 83.
The velocity profile associated with the filtered elbow angular displacement data was computed and the Labview™ front panel was modified to display the results; see Figure 84.
Figure 84: Labview™ Front Panel Design with Velocity Display

The first graph, upper left, displays the elbow and knee angle measurement. The second graph, upper right, displays the angular velocity for the elbow and knee joints. The lower graphs were unmodified.
CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main motivation for this research was the desire to find an appropriate solution to a common problem associated with patient handling. Patient handling can cause bodily injury due to acute or cumulative trauma if tasks are performed incorrectly. The overall objectives of this research were successfully accomplished. The research resulted in the development of an integrated solution using commercially available components to help health care providers handle patients in a safe manner. This was achieved by retrofitting a mannequin with flex sensors, electrogoniometers, pressure sensors and photocells. The final design consisted of the integration of the sensors and the implementation of a LabView™ software based system. Data was collected, stored and analyzed by a virtual instrument, (VI), which was used as the interface between the user or instructor and the instrumented mannequin. The VI, which was developed for this research, possessed the capability of displaying the history of the acquired data. Availability of data history enables the instructor to analyze the sensor information and verify the procedural accuracy of the tasks performed by the student on the simulated patient.
The system developed during this research was also capable of identifying problems such as the application of excessive force or pressure by health care providers when interacting with patients. The system was designed to provide the healthcare community with useful information to improve and provide a safer and more comfortable environment for the patient. Providing the trainer with useful information about the student’s skill building during interaction with a patient will enhance evaluation of the student’s performance.

The results of this research clearly indicate that the instrumented mannequin will be a valuable tool in evaluating and assessing the merits of clinical procedures. The system developed may also be used in biomechanical studies involving patient handling by caregivers.

6.2 Recommendations

Recommendations for future work with Instrumented Mannequins are:

1. Acquire a new mannequin that has more realistic joint movements. In this research, the mannequin did not possess totally realistic joint characteristics. Therefore, the investigation was performed to only limited degrees of freedom within the existing capability of the mannequin’s joints.

2. Design a better mechanical casing that can protect and guide the flex sensor during its movement. It was found during this research that the flex sensor would occasionally stick when it was flexed.

3. Incorporate mechanical limits in the mannequin’s hip joint in order to prevent goniometer damage due to excessive rotation of the sensor.
4. Design and integrate a wireless technology solution. Such a design would eliminate the cables running from the mannequin to the workstation.
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Lippincott Williams & Wilkins, Philadelphia
Appendix A  Examples of Resident Lifting and Repositioning Tasks

A.1 Transfer from Sitting to Standing Position

A.1.1 Description: Powered sit-to-stand or standing assist devices.

A.1.2 When to Use: Use this device when transferring residents who are partially dependent, have some weight-bearing capacity, are cooperative, can sit up on the edge of the bed, with or without assistance, and are able to bend their hips, knees and ankles. Additionally, use the device for transfers of patients from bed to wheelchair, Geri or cardiac, chair to bed or for bathing and toileting. These devices can be used for repositioning where space or storage is limited.

A.1.3 Points to Remember: Look for a device that has a variety of sling sizes, lift-height ranges, battery portability and handheld control with emergency shut-off and manual override. Ensure that the device is rated for the resident’s weight. Electric/battery powered lifts are preferred to crank or pump type devices since they allow smoother movement for the resident and less physical exertion by the caregiver.

A.2 Resident Lifting

A.2.1 Description: The portable sling type lift device can be a universal/hammock sling or a band/leg sling.

A.2.2 When to Use: Use this device for lifting residents who are totally dependent, are partial or non-weight bearing, are very heavy or have other physical limitations. Additionally, use this lift device for transfers from bed to wheelchair, Geri or cardiac, chair or floor to bed, for bathing and toileting or after a resident fall.
A.2.3 Points to Remember: More than one caregiver may be required. Look for a device with a variety of slings, lift-height range, battery portability, hand-held control with emergency shut-off and manual override, a boom pressure sensitive switch that can easily move the equipment and has a support base that goes under beds. Having multiple slings allows one of them to remain in place while the resident is in a bed or a chair for only short periods. The availability of multiple devices reduces the number of times the caregiver lifts and positions resident. Portable compact lifts may be useful where space or storage is limited. Ensure the device is rated for the resident’s weight. Electric/battery powered lifts are preferred to crank or pump type devices in order to allow a smoother movement for the resident, demands less physical exertion by the caregiver and enhances resident safety and comfort.

A.3 Resident Lifting

A.3.1 Description: Ceiling mounted lift device

A.3.2 When to Use: Employ this device when lifting residents who are totally dependent, are partial or non-weight bearing, are very heavy or have other physical limitations. Additionally, use for transfers from bed to wheelchair, Geri or cardiac, chair or floor to bed, for bathing and toileting or after a resident falls. A horizontal frame system or litter attached to the ceiling-mounted device can be used when transferring residents, who cannot be transferred safely otherwise, between two horizontal surfaces such as a bed to a stretcher or gurney while lying on their back.

A.3.3 Points to Remember: More than one caregiver may be needed. Some residents can use the device without assistance. It may be quicker to use than portable device. Motors can be fixed or portable and lightweight. Devices can be operated by a hand-held control that is attached to the unit or by infrared remote control. Ensure the device is rated for the resident weight. These devices increase the residents’ safety and comfort during transfer.
Appendix A (Continued)

A.4 Ambulation

A.4.1 Description: Ambulation assist device

A.4.2 When to Use: For residents who are weight bearing and cooperative and who need extra security and assistance when ambulating.

A.4.3 Points to Remember: This device increases resident safety during ambulation and reduces the risk of falls. The device supports residents as they walk and push it along during ambulation. Ensure that the height adjustment is correct for the resident before ambulation. Ensure that the device is in good working order before use and is rated for the weight of the resident to be lifted. Apply brakes before positioning the resident in or releasing the resident from device.

A.5 Lateral Transfer; Repositioning

A.5.1 Description: A device designed to reduce friction forces when transferring a resident. These devices include draw sheets or transfer cots with handles to be used in combination with slippery sheets, low friction mattress covers or slide boards. Other devices in this category include boards or mats with vinyl coverings and rollers, gurneys with transfer devices and air-assist lateral sliding aids or a flexible mattress, which can be inflated by a portable air supply.

A.5.2 When to Use: Employ these devices when transferring a partial or non-weight bearing resident, positioned on the back, between two horizontal surfaces such as a bed to a stretcher or gurney or when repositioning the resident in bed.
Appendix A (Continued)

A.5.3 Points to Remember: More than one caregiver is required in order to perform this type of transfer or repositioning. Additional assistance may be needed depending upon resident status. For example, additional assistance may be required when moving heavier or non-cooperative residents. Some devices may not be suitable for bariatric residents. When using a draw sheet combination, insure a good handhold by rolling up draw sheets or use other friction-reducing devices with handles such as slippery sheets. Narrower slippery sheets with webbing handles positioned on the long edge of the sheet may be easier to use than wider sheets. When using boards or mats with vinyl coverings and rollers use a gentle push and pull motion to move the resident to new surface. Look for a combination of devices that will increase the resident’s comfort and minimize risk of skin trauma. Ensure transfer surfaces are at the same level and at a height that allows caregivers to work at waist level to avoid extended reaches and bending of the back. Count down and synchronize the transfer motion between caregivers.

A.6 Lateral Transfer; Repositioning

A.6.1 Description: Convertible Geri or cardiac wheelchairs and beds that convert to chairs.

A.6.2 When to Use: Use these devices for lateral transfer of residents who are partial or non-weight bearing. These devices eliminate the need to perform lift transfer in and out of wheelchairs. They can also be used to assist residents who are partially weight bearing from a sit-to-stand position. Beds that convert to chairs can aid in the repositioning of residents who are totally dependent, non-weight bearing, very heavy or those with other physical limitations.

A.6.3 Points to Remember: More than one caregiver is required to perform a lateral transfer. Depending on resident status, additional assistance for lateral transfers may be required. For example, additional assistance may be required when moving heavier or non-cooperative residents. Additional friction-reducing devices may also be required to reposition a resident. Heavy-duty beds are available for bariatric residents. Device should have easy-to-use controls located within easy reach of the caregiver, sufficient foot clearance and wide ranges of adjustment. Motorized height adjustable devices are preferred to those adjusted by a crank mechanism to minimize physical exertion. Always ensure that the
device is in good working order before use. Ensure that the wheels associated with the equipment are properly locked. Ensure that transfer surfaces are at the same level and at a height that allows caregivers to work at waist level in order to avoid extended reaches and bending of the back.

A.7 Repositioning in a Chair

A.7.1 Description: Variable position Geri and Cardiac wheelchairs

A.7.2 When to Use: Use these devices when repositioning partial or non-weight-bearing residents who are cooperative.

A.7.3 Points to Remember: More than one caregiver is required and use of a friction-reducing device is needed if the resident cannot assist in the reposition activity. Ensure the use of good body mechanics by caregivers. The wheels on chair add versatility. Ensure that the chair is easy to adjust, move and steer. Lock the chair’s wheels before repositioning. Remove trays, footrests and seat belts, where appropriate. Ensure that the device is rated for the resident’s weight.

A.8 Lateral Transfer in a Sitting Position

A.8.1 Description: Transfer boards; wood or plastic. Some boards are equipped with a movable seat.

A.8.2 When to Use: Use these devices when transferring or sliding residents who have good sitting balance and are cooperative. Such transfers are from one level surface to another such as from bed to wheelchair, wheelchair to car seat or toilet. Residents who require limited assistance but need additional safety and support can also use these devices.

A.8.3 Points to Remember: Movable seats increase resident comfort and reduce the incidence of tissue damage during transfer. More than one caregiver is needed to perform a lateral transfer.
Appendix A (Continued)

Ensure that clothing is present between the resident's skin and the transfer device. The seat may be cushioned with a small towel for comfort. Such a transfer may be uncomfortable for larger residents. Depending on resident's status, these devices are usually used in conjunction with gait belts for safety. Ensure that boards have tapered ends, rounded edges and the appropriate weight capacity. Ensure that the wheels on the bed or chair are locked and that transfer surfaces are at the same level. Remove the lower bedrails from a bed and remove the arms and footrests from chairs as appropriate.

A.9 Transfer from a Sitting to a Standing Position

A.9.1 Description: Devices include lift cushions and lift chairs.

A.9.2 When to Use: These devices are used when transferring residents who are weight bearing and cooperative but require assistance when standing and ambulating. Such devices can also be used for independent residents who require an extra boost in order to stand.

A.9.3 Points to Remember: Lift cushions employ a lever that activates a spring action in order to assist residents in the activity of moving to a standing position. Lift cushions may not be appropriate for heavier residents. Lift chairs are operated via a handheld control that tilts the chair forward slowly while raising the resident. Residents need to have physical and cognitive capacity to be able to operate a lever or other controls. Always ensure that the device is in good working order before use and that it is rated for the weight of the resident to be lifted. These devices provide the resident with a measure of independence.

A.10 Transfer from a Sitting to a Standing Position

A.10.1 Description: Stand-assist devices can be fixed to a bed or chair or be freestanding.

A.10.2 When to Use: Use these devices when transferring residents who are weight-bearing, cooperative and who can pull themselves up from a sitting to a standing position. These devices can be used for independent residents who require extra support in order to stand.
Appendix A (Continued)

A.10.3 Points to Remember: Check that the device is stable before use and is rated for the weight of the resident to be supported. Ensure that the frame is firmly attached to bed. If the device must rely on mattress support ensure that the mattress is heavy enough to hold the frame. These devices can provide the resident with a measure of independence.

A.11 Weighing

A.11.1 Description: Scales with ramps to accommodate wheelchairs, portable powered lift devices with built-in scales and beds with built-in scales.

A.11.2 When to Use: Use these devices to reduce the number of transfers of partial or non-weight-bearing residents or totally dependent residents to weighing device.

A.11.3 Points to Remember: Some wheelchair scales can accommodate larger wheelchairs. Built-in bed scales may increase the weight of the bed and prevent it from lowering to appropriate work heights.

A.12 Transfer from a Sitting to a Standing Position; Ambulation

A.12.1 Description: Gait belts/transfer belts with handles.

A.12.2 When to Use: Use these devices when transferring residents who are partially dependent, have some weight-bearing capacity and are cooperative. Employ these devices for transfers such as bed to chair, chair to chair, chair to car, repositioning residents in chairs, supporting residents during ambulation, and in some cases when guiding and controlling falls or assisting a resident after a fall.

A.12.3 Points to Remember: More than one caregiver may be required. Belts with padded handles are easier to grip and
Appendix A (Continued)

increase security and control. Always perform the transfer to the resident's strongest side. Use good body mechanics along with a rocking and pulling motion rather than lifting directly when using a belt. Belts may not be suitable for ambulation of heavy residents. Belts should not be used for lifting residents with recent abdominal or back surgery or those with an abdominal aneurysm. Ensure that the belt is securely fastened and cannot be easily undone by the resident during transfer. Ensure that a layer of clothing is between the resident's skin and the belt in order to avoid abrasion. Keep the resident as close as possible to the caregiver during transfer. Be sure to lower bedrails, remove arms and footrests from chairs and any other items that could obstruct the transfer. If a belt is to be used after a fall always assess the resident for injury prior to movement. If the resident can regain a standing position with minimal assistance, use gait or transfer belts with handles to aid the resident. Keep the back straight, bend legs and stay as close to the resident as possible. If the resident cannot stand with minimal assistance, use a powered portable or ceiling-mounted lift device to move the resident.

A.13 Repositioning

A.13.1 Description: Electric powered height adjustable beds.

A.13.2 When to Use: Use these devices for all activities involving resident care, transfer or repositioning in the bed. These devices reduce caregiver bending when interacting with the resident.

A.13.3 Points to Remember: The device should have easy-to-use controls, which are located within easy reach of the caregiver to promote use of the electric adjustment, sufficient foot clearance and wide ranges of adjustment. Adjustments must be completed in 20 seconds or less to ensure staff use. Beds that lower closer to the floor may be required for residents that may be at risk of falling from bed. Heavy-duty beds are available for bariatric residents. Beds raised and lowered with an electric motor are preferred over crank-adjust beds in order to allow a smoother movement for the resident and less physical exertion for the caregiver.
Appendix A (Continued)

A.14 Repositioning

A.14.1 Description: Trapeze bar; hand blocks and push up bars attached to the bed frame.

A.14.2 When to Use: Use these devices to reposition residents that have the ability to assist the caregiver during the activity. These devices are particularly appropriate for residents with upper body strength, maintain the use of extremities, are cooperative and can follow instructions.

A.14.3 Points to Remember: Residents use the trapeze bar by grasping the bar while it is suspended from an overhead frame in order to raise them up and reposition them in a bed. Heavy-duty trapeze frames are available for bariatric residents. If a caregiver is assisting, ensure that the bed wheels are locked, bedrails are lowered and the bed is adjusted to the caregiver's waist height. Blocks also enable residents to raise themselves up and reposition themselves in bed. Bars attached to the bed frame serve the same purpose. These devices may not be suitable for heavier residents. Such devices can provide the resident with a measure of independence.

A.15 Repositioning

A.15.1 Description: Pelvic lift devices (hip lifters).

A.15.2 When to Use: Use these devices to assist residents who also are cooperative and can sit up to a position on a special bed pan.

A.15.3 Points to Remember: Use of the device may reduce the need for resident lifting during toileting. The device is positioned under the pelvis. The part of the device located under the pelvis gets inflated so the pelvis is raised and a special bedpan is put underneath. The head of the bed is raised slightly during this procedure. Use correct body mechanics, lower bedrails and adjust the bed to the caregiver’s waist height in order to reduce bending.
Appendix A (Continued)

A.16 Bathtub, Shower, and Toileting Activities

A.16.1 Description: Height adjustable and easy-entry bathtubs.

A.16.2 When to Use: Use these devices when bathing residents who can sit directly in the bathtub or to assist ambulatory residents to enter into a low tub, or easy-access tub more easily. Bathing residents in portable-powered or ceiling mounted lift device requires the use of and appropriate bathing sling.

A.16.3 Points to Remember: These devices reduce awkward postures for caregivers and those who clean the tub. The tub can be raised to eliminate bending and reaching for the caregiver. Use correct body mechanics and adjust the tub to the caregiver's waist height when performing hygiene activities. Use of these devices increase resident safety and comfort.

A.17 Bathtub, Shower, and Toileting Activities

A.17.1 Description: Height adjustable shower gurney or lift bath cart with waterproof top.

A.17.2 When to Use: Use these devices for bathing non-weight bearing residents who are unable to sit up. Transfer the resident to a cart that is equipped with lift or lateral transfer boards or other friction-reducing devices.

A.17.3 Points to Remember: The cart can be raised to eliminate bending and reaching for the caregiver. Foot and head supports are available for resident comfort. These devices may not be suitable for bariatric residents. Look for carts that are power-driven in order to reduce the force required to move and position the device.
Appendix A (Continued)

A.18 Bathtub, Shower, and Toileting Activities

A.18.1 Description: Built-in or fixed bath lifts.

A.18.2 When to Use: Use these devices when bathing residents who are partially weight bearing, have good sitting balance, can use their upper extremities, are cooperative, and can follow instructions. These devices are useful in small bathrooms where space is limited.

A.18.3 Points to Remember: Ensure that the seat rises sufficiently for the resident's feet to clear the tub, rotates easily and lowers properly in order to place the resident into the water. Such devices may not be suitable for heavy residents. Always ensure that the lifting device is in good working order before use and is rated for the resident's weight. Choose a device with a lift mechanism that does not require excessive effort by the caregiver when raising and lowering device when it is occupied by a resident.

A.19 Bathtub, Shower, and Toileting Activities

A.19.1 Description: Shower and toileting chairs.

A.19.2 When to Use: Use these devices when showering and toileting residents who are partially dependent, have some weight bearing capacity, can sit up unaided and who are able to bend their hips, knees, and ankles.

A.19.3 Points to Remember: Ensure that the chair wheels move easily and smoothly and that the chair is high enough to fit over the toilet. Additionally, ensure that the chair has removable arms, adjustable footrests, safety belts, is heavy enough to be stable, the seat is comfortable, accommodates larger residents and has a removable commode bucket for toileting. Ensure that brakes lock, hold effectively and that the weight capacity is adequate.
Appendix A (Continued)

A.20 Bathtub, Shower, and Toileting Activities

A.20.1 Description: Bath boards and transfer benches.

A.20.2 When to Use: Use these devices when bathing residents who are partially weight bearing, have good sitting balance, can use their upper extremities, are cooperative and can follow instructions. Independent residents can also use these devices.

A.20.3 Points to Remember: To reduce friction and possible skin tears insert clothing or material between the resident’s skin and the board. These devices can be used with a gait or transfer belt and/or grab bars to aid transfer. Back support and vinyl-padded seats add to the resident’s bathing comfort. Look for devices that provide for water drainage and have height-adjustable legs. These devices may not be suitable for heavy residents. If a wheelchair is used ensure that the wheels are locked, the transfer surfaces are at the same level and the device is securely in place and rated for the weight to be transferred. Remove arms and footrests from chairs as appropriate and ensure that the floor is dry.

A.21 Bathtub, Shower, and Toileting Activities

A.21.1 Description: Toilet seat risers.

A.21.2 When to Use: Use these devices for toileting partially weight-bearing residents who can sit up unaided, use their upper extremities, are able to bend their hips, knees, and ankles and are cooperative. Independent residents can also use these devices.

A.21.3 Points to Remember: Risers decrease the distance and amount of effort required to lower and raise residents. Grab bars and height-adjustable legs add safety and versatility to the device. Ensure that the device is stable and can accommodate the resident’s weight and size.
Appendix A (Continued)

A.22 Bathtub, Shower, and Toileting Activities

A.22.1 Description: Grab bars and stand assists; fixed or mobile, long-handled or extended showerheads and brushes used for personal hygiene.

A.22.2 When to Use: Use devices such as bars and assists to help when toileting, bathing, and/or showering residents who need extra support and security. Residents must be partially weight bearing, able to use their upper extremities and be cooperative. Long-handled devices reduce the amount of bending, reaching and twisting required by the caregiver when washing the feet, legs and trunk of a resident. Independent residents who have difficulty reaching lower extremities can also use these devices.

A.22.3 Points to Remember: Movable grab bars on toilets minimize workplace congestion. Ensure that bars are securely fastened to the wall before use.