Design and Development of Automated Mannequin

"A Final Year Project Report"

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Abstract

"Mannequin" is an old invention. It entered garments industry in 1950s and revolutionized marketing techniques in garments industry. It had two major impacts on garments industry:

1. A Dressmaker's assistant who wears new costumes to display them for sale in dressmaking houses
2. An attention seeker

Its current role in garments industry is completely different from its initial role i.e. just a decoration item and it is the reason why it is not playing any role in garments industry.

We have made a robotic mannequin, one compatible with current era of technology so that it can again play its role in garments industry and it once again revolutionizes marketing techniques in garments industry. We have made it an attention seeker to fulfill marketing needs of garments and fashion industry.

After doing a detailed research and study we have installed 5 independent actuators in 5 different joints thus giving it 5 DOF. It has following joints:

- Right Shoulder joint
- Left shoulder joint
- Right wrist joint
- Left wrist joint
- Pelvis joint

Mannequin is a highly customizable product and market needs customized product designed for that particular place. Keeping this all in mind, Degrees of Freedom on mannequin can vary.

We expect that this product will fulfill marketing needs of garments and fashion industry and this mannequin will contribute to its fullest to garments and fashion industry.

The present invention relates to a mannequin that is to be installed in a show window, at a point of sale, in the vicinity of merchandises or the like, and particularly to a mannequin having a automated joints installed in the arms, etc. of the mannequin

Contents

Acknowledgement

“**In the name of Allah, the Beneficent, the Merciful. Praise be to Allah, Lord of the Worlds,”** **(**The Holy Quran, Surah Fatiha, Verse 1**)**

We wish to express our sincere gratitude to **Dr. Yasar Ayaz**, Faculty of National University of Science and Technology. **School of Mechanical and Manufacturing Engineering** for providing us an opportunity to do final year project work on **“Design and Development of Automated Mannequin”.**

This project bears on imprint of many peoples. We sincerely would like to thank our project guide **Col. Naveed** Ikram, Director Manufacturing Resource Center **MRC**, National University of Science and Technology & **Dr. Muhammad Naveed,** Faculty SMME, National University of Science and Technology for guidance and encouragement in carrying out this project work.

We are also thankful to **Mr. Fahad Iqbal**, Faculty SMME, National University of Science and Technology for helping and streamlining us throughout the project.

We also wish to express our gratitude to our friends who rendered their help during the period of our project work.

INDTRODUCTUION

“Mannequin” is an old invention. It entered garments industry in 1950s and revolutionized marketing techniques in garments industry. It had two major impacts on garments industry:

1. A Dressmaker's assistant who wears new costumes to display them for sale in dressmaking houses
2. An attention seeker

Problem Statement

Its current role in garments industry is completely different from its initial role i.e. just a decoration item and it is the reason why it is not playing any effective role in garments industry.

Objectives

The present invention relates to a mannequin that is to be installed in a show window, at a point of sale, in the vicinity of merchandises or the like, and particularly to a mannequin having a automated joints that varies it configurations.

Proposed Solution

We have made a robotic mannequin, one compatible with current era of technology so that it can again play its role in garments industry and it once again revolutionizes marketing techniques in garments industry. We have made it an attention seeker to fulfill marketing needs of garments and fashion industry.

REVIEW OF LITERATURE

After doing a detailed research and study five joints were decided to be automated, thus giving it 5 DOF

- Right Shoulder joint
- Left shoulder joint
- Right wrist joint
- Left wrist joint
- Pelvis joint

Mannequin is a highly customizable product and market needs customized product designed for that particular place. Keeping this all in mind, Degrees of Freedom on mannequin can vary.

Structure of Mannequin

Two options were pointed to get the body of mannequin.

1. Design a mannequin for this purpose and get it manufactured from the market .
2. Get a static mannequin available in the market and modify it according project objectives.

Latter option was chosen by the team as designing and manufacturing of mannequin is a tedious task and extremely expensive as well, where as purchasing cost effective and easy task. Besides this designing and manufacturing of mannequin is a distraction from core objectives of project.

Market surveyed was conducted for available manufacturers of mannequins. There are two manufacturers of mannequins in Pakistan.

- Anjum Mannequins

- Sialkot Mannequins

Details of mannequins of both companies are listed in table below:

Property	Anjum Mannequins	Sialkot Mannequins
Material	Fiber Glass	Acrylic Glass
Weight	10-12 Kg	12-15 Kg
Weight of hands	1.6 – 2 Kg	2-2.2 Kg
Thermal strength	Upto 65 degrees (without metal contact)	Upto 65 degrees (without metal contact)
Machining property	Tough machining	Tough machining
Joints	Head + Shoulders +waist line + Wrist	Head + Shoulders +waist line
Price	Upto Rs. 6500/-	Upto Rs. 9000/-

After finding these properties of both companies, we got samples from both companies and discussed it with our supervisor and Lt. Col (R) Naweed Hassan, Deputy Director, Manufacturing Resource Centre (MRC) and came to a conclusion that we should buy a mannequin from Anjum mannequin because:

- Fiber glass is a better option for machining and modifications
- It is light weighted
- It already has additional wrist joint
- Economically it is more feasible

Mechanical Properties

Material

Material used for the manufacturing of the mannequin is Poly-Fiberglass, with 40% composition of Fiberglass.

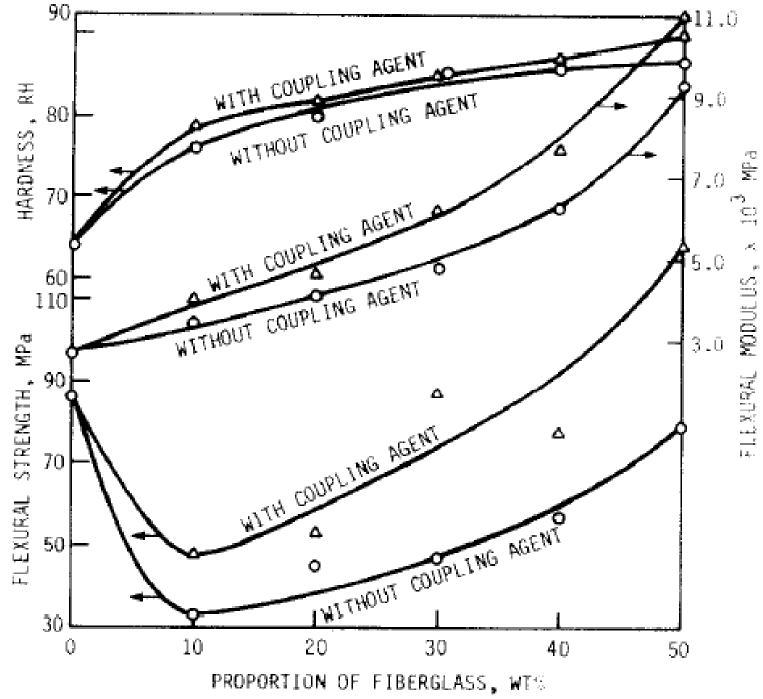
Material Description

Poly-Fiberglass is basically polyester re-enforced with fiberglass in different compositions (usually 10%-60% with increment of 10 wt% of fiberglass).

Most common composition of poly-fiberglass used for mannequin dummies is with 40 wt% of fiberglass.

Material Properties

The effect of reinforced polyester with fiber glass in terms of resulting mechanical properties was used from already conducted study. The flexure tests were conducted according to the ASTM Standard D790 using a cross-head speed of 2.8 mm min^{-1}. The specimen was secured to cylindrical loading with to strain gauges mounted on its opposite sides



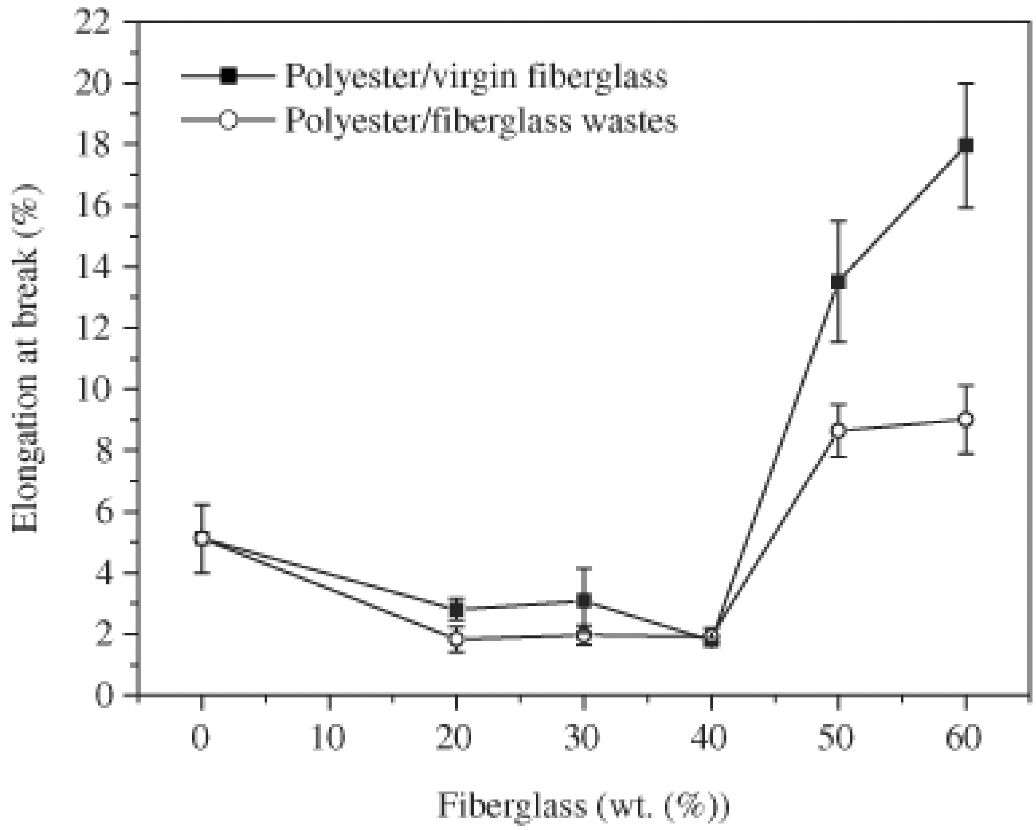


Figure 2. Elongation at break of polyester/fiberglass composites.

Fiberglass = 40 wt%

Flexural Modulus = 6.8 GPa

Flexural Strength = 54 MPa

Elongation at Breakage = 2.2%

Dimensions of Hands

Shoulder to Elbow length = 0.31m

Elbow to Wrist length = 0.2m

Wrist to Fingertip length = 0..2m

Average diameter of hand = 66mm

Thickness of Sheet = 2mm

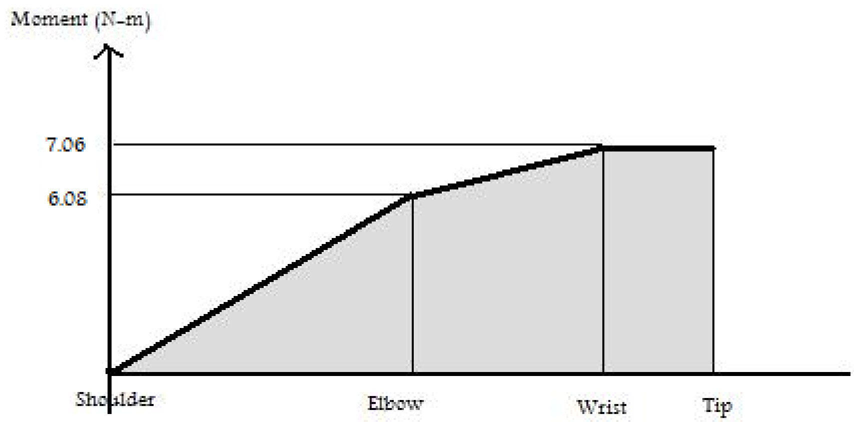
*Center of Gravity of hand lies at Elbow

**A motor of max 500 grams to be installed at wrist

Mechanics of body

Since legs, pelvis and head are firmly attached to the frame with no reaction or hanging moments, they are mechanically stable.

Although according to our model hand is hanging in air like cantilever beam with its load at center of gravity and load of a motor at wrist. Bending moment diagram of hand in horizontal position (when it has maximum bending) is given below.



Maximum Allowable Moment

$$\mathbf{M}_{max} = \boldsymbol{\sigma}_{max} \times \mathbf{S}$$

$$S = \frac{I}{r}$$

$$I = \frac{1}{2} pi \, (r^4 - r_i^4)$$

$$\mathbf{M}_{max} = 675\text{N-m}$$

$$\mathbf{M'_{max} = 225N\text{-}m} \qquad \text{(Factor of Safety=3)}$$

Actual Maximum Elongation

$$\sigma_{am} = \frac{M_{am}}{S}$$

$$\delta_{am} = \frac{\sigma_{am}}{E}$$

$$\delta_{am} = 0.00008 \ (\mathbf{0.008}\%) < \mathbf{2\%}$$

$\sigma_{am}, M_{am}, \delta_{am}$ are actual maximum stress, moment and elongation respectively.

Where E is Flexural Modulus.

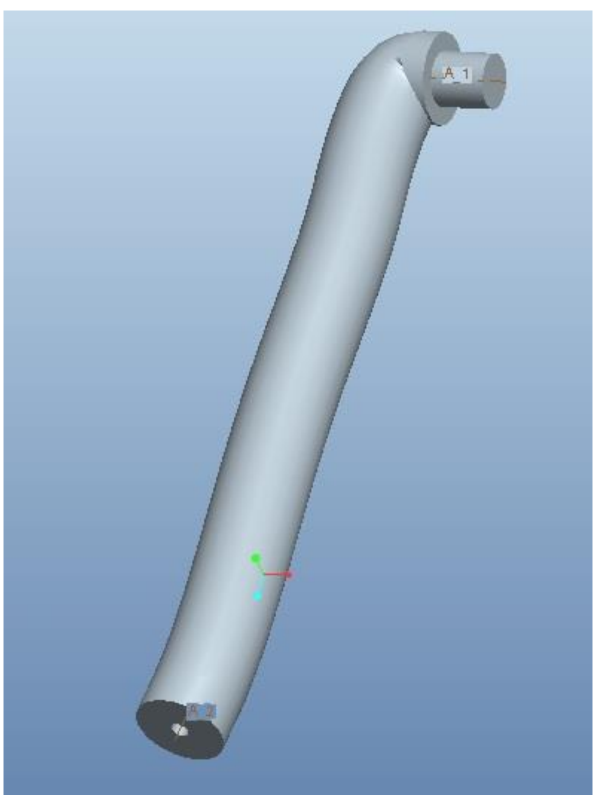
From above result we can safely assume our hand is safe of breakage.

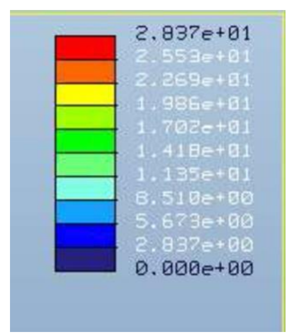
A still arm with maximum bending moment is stable. Although when arm is moving, maximum torque of motor should not exceed 225N-m.

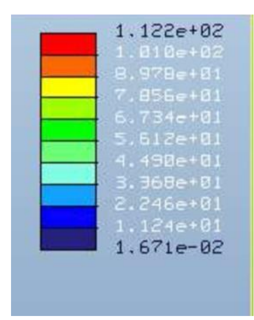
There is no torsion expected as free end of arm is not subjected to any moment about axis of arm.

CAD Analysis

CAD analysis was also done to check the stability of arm







Motion Strategy

To achieve a moving joint of mannequin's different techniques were studied that are generally used for robotic motions.

Core of motion in a robotic system are actuators which are mostly hydraulic, pneumatic or motors. Hydraulic and pneumatic systems are not feasible for our project since there heavy system associated with them and taking a delicate product to market with heavy machinery controlling it is neither cost effective nor market friendly. This product is only feasible to maintain in market if joints are actuated with motors.

Motors that are generally used in robotic applications with light weight systems, like mannequins, are DC driven and are of three types

- Servo Motors
- Simple DC Motors
- Stepper Motors

To choose or reject different types of motor, the aspects taken into account were.

- Ability to bear the load
- Physical limitations
- Complexity of control

Servo motors are most easy to control and achieve desired position, but are only available for very light load application and they require a constant power input and signal to retain a position. Since they can't bear high loads so they are totally ruled out for driving pelvis joint. Although they may be used to drive shoulder or wrist joints but continuous power supply is an issue due to frequent power outages they can't be installed in shoulder joints as heavy arms will not be able to retain their position in such circumstances.

DC motors can bear load and are moderate to control, but they lack ability to hold the load at desired position unless assisted with electronic and mechanical auxiliaries. Moreover their speed can easily be varied keeping in mind the requirements of objectives.

Stepper motors can bear high load, but they also require constant power input for holding joints in their positions and are very complex to control. Due to complex control these types of motors are ruled out as controller channels pre-occupied for other tasks and minimum channels are available for control of motors.

After analyzing these properties of different motors and project requirements, different types of motors are decided to be most suitable for different joints.

Wrist is most suitably to be driven using a servo motor, since loading on wrist joint is very less and it can retain its position in case of power outage. Although servo motor can help in control, as it make control very simple. Position can easily be varied by varying PWM on control bit of motor. So only two PWM channel are required of controller for this purpose.

For shoulder joints, servos aren't the best option as retaining position of an arm with considerable load in this case. On other hand using DC motors with auxiliaries to retain position and control speed is better option. Feedback is taken through dead reckoning.

For pelvis joint similar approach to that for shoulder joint is best option i.e. installing DC motors with auxiliaries and dead reckoning techniques.

Auxiliaries

Mostly there are two categories of auxiliaries to be used with simple DC motors to control the speed and retain the position.

- Electronic Auxiliaries
- Mechanical Auxiliaries

Electronic auxiliaries include PWM control, PID chips etc. but they also hold the physical limitation like power outages, frequent bugging and sensitive to heat etc.

Mechanical auxiliaries are different types of gearing mechanism. Required speed is attained through gear ratios, whereas position is mostly retained by installing worm wheel gears.

Dead Reckoning

Dead reckoning for position is done by simple feedback instruments like potentiometer, limit switches, contact sliders and disk encoders. Disk encoders are mostly used in robotic applications as they are free of calibration, accurate, simple to read for controller input.

Control Systems

All our tools and machines need appropriate control to work, otherwise it will be difficult to finish their designated tasks accurately. Therefore, we need control systems to guide, instruct and regulate our tools and machines. Common control systems include mechanical, electronic, pneumatic and computer aided control systems. A system usually contains three main parts: input, process and output.

(a) Mechanical system

A mechanical system is a device made up of various mechanical parts. Its input is provided by an effort. Once the effort and is applied, it can set off a motion to move a load. The force applied to the load is the output of the mechanical system. Examples of mechanical systems include levers, gears and shafts. Fig. 1 shows some examples of mechanical systems.

(a) Can opener

(b) Corkscrew

Fig. 1 Examples of mechanical systems

(b) Electronic system

An electronic system is a system that employs electronic signals to control devices, such as radios, calculators, video game machines, mobile phones, portable computers, etc (Fig. 2). The input of an electronic system is provided by electronic signals. After they are processed, they can generate output signals, which control the operation of various devices, such as actuators, sensors, etc. Electronic systems can carry out many different tasks, such as generating sound, processing information, transmitting signal to other devices, measuring, memorizing, calculating, etc. Common examples of electronic devices include semi-conducting diode, transistors, and capacitors that they are usually soldered onto electronic circuit boards (Fig. 3).

(a) Mobile phone (b) Portable computer

Fig. 2 Examples of electronic systems

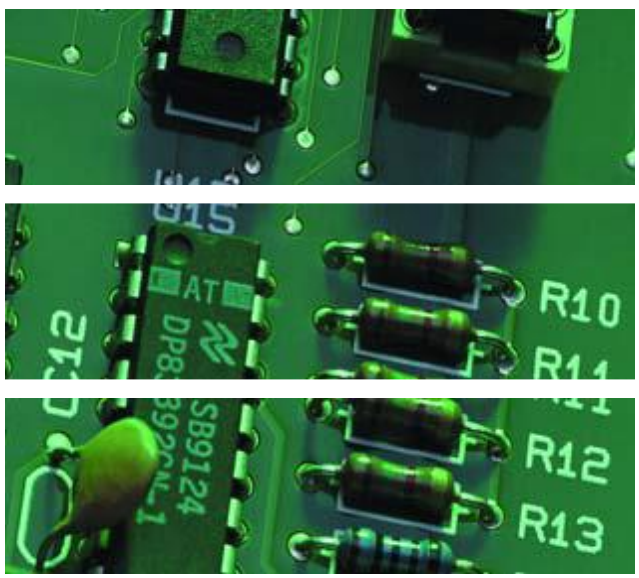
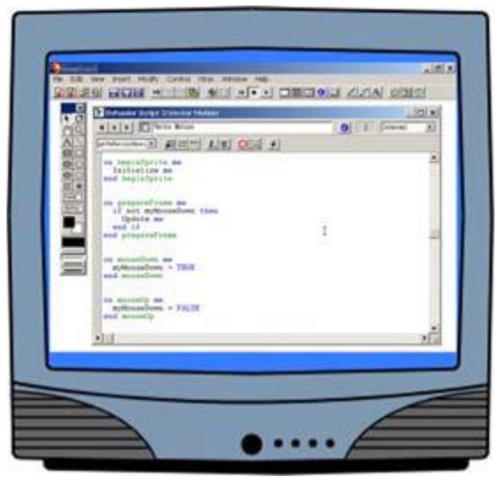


Fig. 3 Electronic circuit board

(c) Computer control system

A computer control system uses a computer to control its output devices according to different input signals. Its function is similar to that of an electronic system. Yet a computer control system can use high speed calculation to process large volume of input signals within a very short time, and then generates appropriate outputs with the help of preset programs. Examples of computer control systems include computer numerical control press brakes, computer controlled home appliances, computer controlled underground railway systems, etc (Fig. 4).

(a) CNC press brake

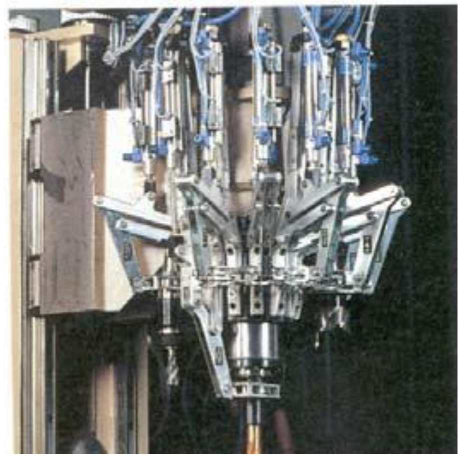


(b) A proposed computer controlled home appliances

Fig. 4 Examples of computer control systems

(d) Pneumatic system

A pneumatic system is a system that uses compressed air to transport and control energy. Air is first pressurized to give energy in the cylinder. Then signals are input into the system through the use of switches. Next, air is transferred through sealed pipes to the pneumatic parts for processing. Finally, the force produced by the pneumatic parts is utilized to finish the designated task. The use of pneumatic systems is very extensive, for example, in controlling the movement of train doors, the operation of automatic production lines and mechanical clamps, etc (Fig. 5).



(a) Production line of CD-ROM (b) Mechanical clamp

Fig. 5 Examples of pneumatic systems

(e) Other systems

There exist many other control systems apart from the ones mentioned above, for example, mail processing systems, commercial operation systems, etc. The input, process and output of different systems have different properties. In this chapter, we will discuss some of the most common control systems.

Selection of Control System:

We cannot use mechanical systems in our application as we need to automate mannequin and make it independent of any external force needed to move its joints. Computer control is quite similar to required type of control but it is suitable for high processing needs and our application does not has that much needs. Pneumatic system could be used in our application but it needs quite a number of accessories like compressor, pumps, etc. which adds to required space by the product and it is more costly to be applied in a mannequin. In addition to all above mentioned issues, Its accessories are not readily available in local market which again adds to the cost of the product and time needed for any operation most of the parts have to be imported in case of pneumatic control system.

In contrast to all above mentioned types of control systems, Electronic Control system is most suitable type of system for our application because:

- It has a compact size
- It has a relatively simple design and operation
- It has a long life span and is quite durability
- Its versatility of application

There are two major types of Electronic Control systems:

- PLC based control
- Microprocessor based control

PLC based control requires more expertise in the field and more time to design and apply its control. In contrast, our group had some prior knowledge regarding Microprocessor based control and thus it was easier for us to apply in our project and more over, it has cheaper parts as compared PLC based control.

After deciding to use a Microprocessor based control, next task is to select a suitable microprocessor for our project. Selection of microprocessors is done on the following basis:

- Modules required
- Processing Requirement
- Type of channels required
- Number of channels required
- Availability
- Cost

We needed PWM module to control speed of DC motors and operate Servo motors. We also needed external interrupt pins and timers to read data from encoders and decode it. We further needed Input output ports. Another extremely important factor in selection of microprocessor is availability of microprocessor in local market. If a microprocessor is not available in local market, its selection will add to both time and cost of project. We short listed microprocessors locally available with these specifications. There are two major companies of Microprocessors.

- Atmel
- Microchip

We short listed microprocessors of these two companies. Following is the list of shortlisted microprocessors.

- ATmega48
- ATmega88
- ATmega168
- ATmega328
- ATmega1284

All of these microprocessors are locally available and meet our desired specifications. Now we made final selection on the basis of cost. It is the most important factor of failure or success of any product.

Following are prices of these microprocessors along with their vendors.

Micro controller	**evselectro**	**digipak**	**roboticspk.com**
ATmega48	225	290	
ATmega88	250		
ATmega168	430		
ATmega328	415	400	200

Micro controller	evselectro	digipak	roboticspk.com
ATmega1284.		2000	

Thus we selected ATmega48 to be used in our project. Following are detailed specifications of ATmega48

.

Peripheral features

– Two 8-bit timer/counters with separate prescaler and compare mode

– One 16-bit timer/counter with separate prescaler, compare mode, and capture mode

– Real time counter with separate oscillator

– Six PWM channels

– 8-channel 10-bit ADC in TQFP and QFN/MLF package

– 6-channel 10-bit ADC in PDIP Package

– Programmable serial USART

– Master/slave SPI serial interface

– Byte-oriented 2-wire serial interface (Philips I2C compatible)

– Programmable watchdog timer with separate on-chip oscillator

– On-chip analog comparator

– Interrupt and wake-up on pin change

Special microcontroller features

– DebugWIRE on-chip debug system

– Power-on reset and programmable brown-out detection

– Internal calibrated oscillator

– External and internal interrupt sources

– Five sleep modes: Idle, ADC noise reduction, power-save, power-down, and standby

METHODOLOGY

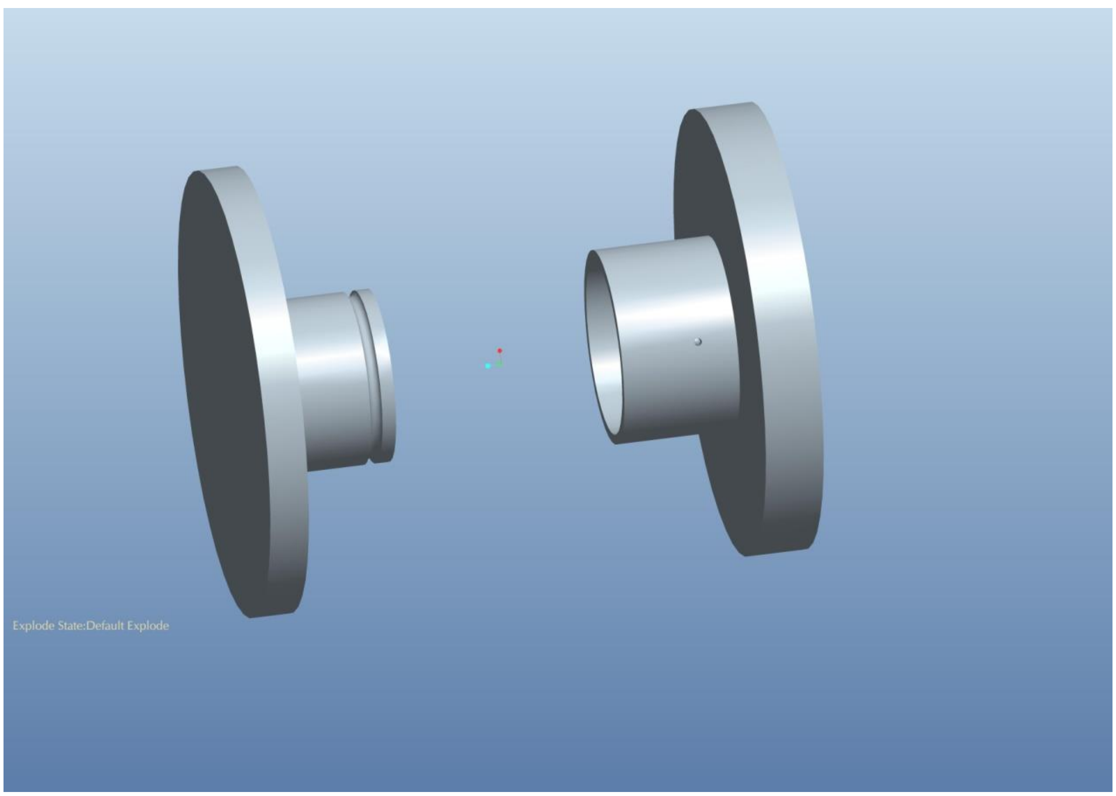
Procurement of Structure

As per decided according to the survey mannequin was purchased from Anjum Mannequins.

Installation of Joints & Actuators

New joints were designed to be installed in mannequins, so that they can be derived through pre-decided actuators.

Wrist joint was derived with servo motor for this purpose load. Motor had to bear 0.35 kg of axial load. To bear this load “Tower-Pro 9-g” servo motor was installed which can bear 1.6 kg axial load. To install this motor a coupling as shown in the figure was designed so motor can derive hand using that coupling as a link.

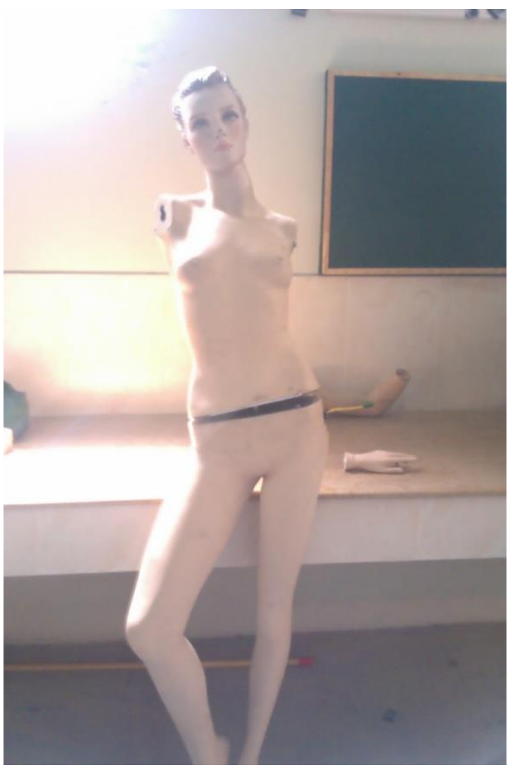


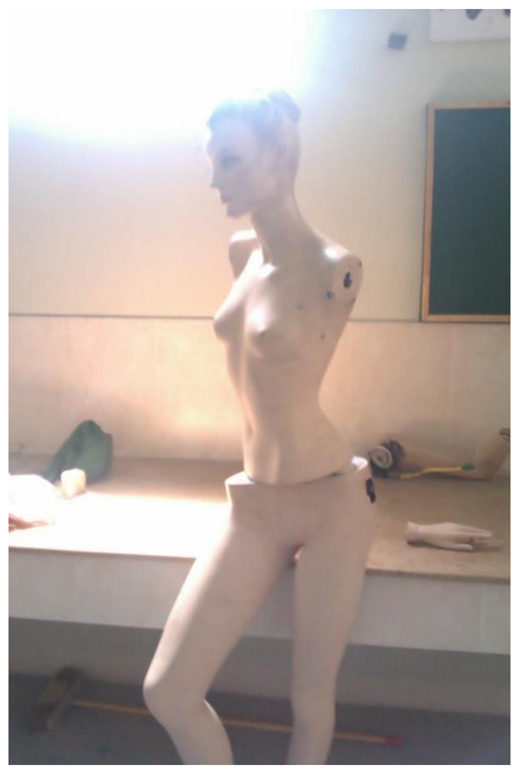
In this joint motor is installed in the arm and coupling set is installed both in arm as well as hand such that coupling rotate over each other. A screw is inserted n outer part of coupling and it slide in slot of inner part of coupling to counter any lateral loading.

Shoulder joint was driven by DC motor. Drive chain was assisted by a set of worm wheel gear. Worm wheel gear was installed in drive chain for speed reductions speed reduction, and keeping arm still in case no power is applied. For this purpose Mitsubishi motor used for power windows in automobile applications were used. These motors deliver output power of 40 kg-cm, whereas the requirement to lift and arm under maximum loading was 22 kg-cm. Feedback for control was taken through disk encoders with 2 bit c-type IR sensors. Secondary reduction control was done through controller

To couple the motor with arm original shaft of the motor was modified and extended to meet the mating plate of shoulder. Ends of the shaft were riveted to the plate thus whenever the motor is derived it rotates the arm.

Pelvis joint was also derived through DC motors with high reduction gear box. For this joint two matting plates were installed in the pelvis. Motor was fixed to the lower plate such that it seated in lower part of mannequin. Shaft of the motor was coupled with the housing fixed to the upper plate. It was designed to rotate maximum of 15 degree. Feedback for the controller was taken through the same type of encoder used for shoulder joints.



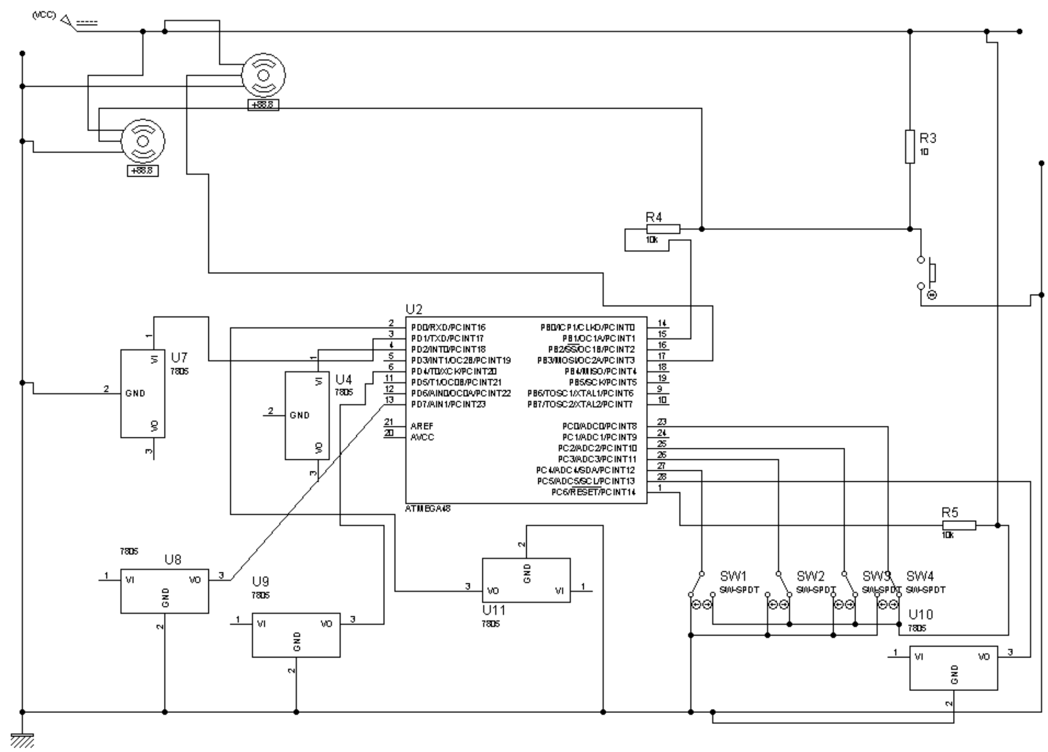


Home Pelvis Position Extreme Pelvis Position

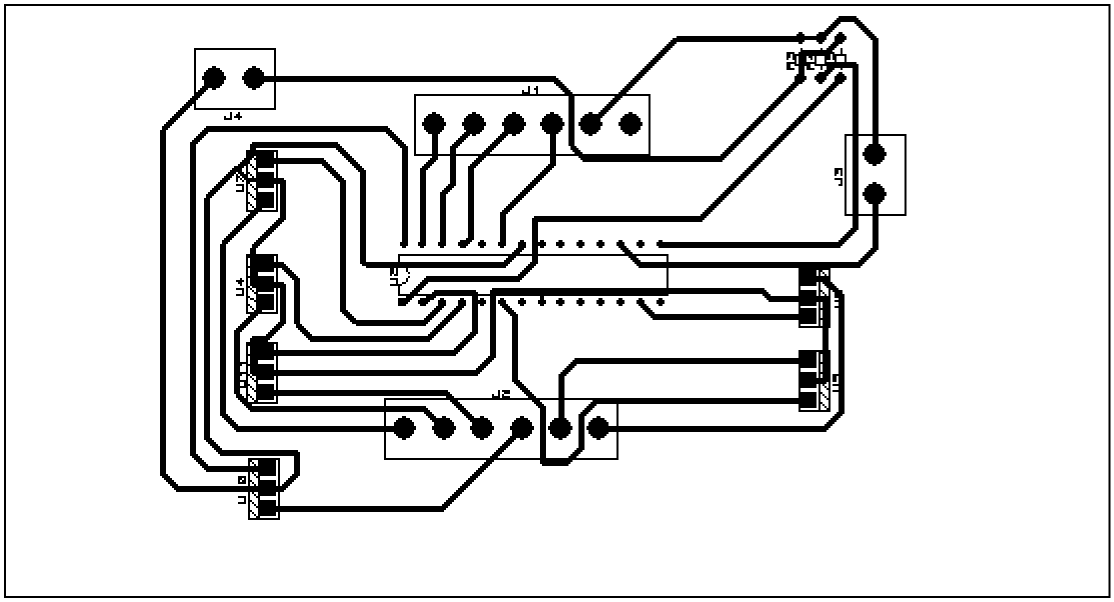
Development of Control

All the decisions were taken through ATMega-48 Microcontroller. Two servos of wrist were controlled through two PWM channels. DC motors for shoulders and pelvis were derived through H-Bridges and each H-Bridge was controlled through one PWM channel and one output channel using swap technique. Six input channels were dedicated for feedback of DC motors.

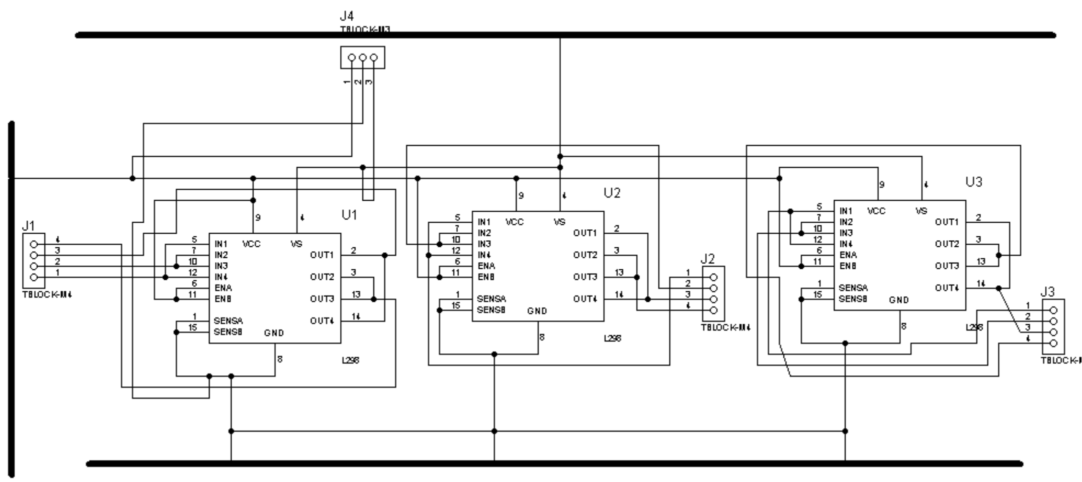
Circuits



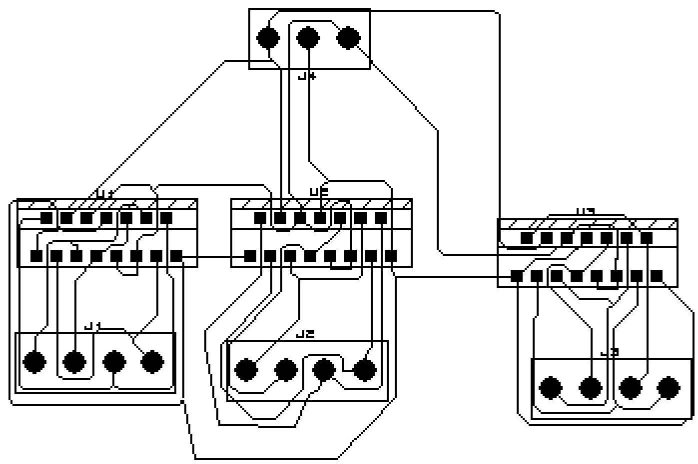
Control board schematic



Control Board PCB Layout



H-Bridges Schematic



H-Bridges PCB Layout

Pseudo Code

Start

Initialize current position and desired position variable for each joint

Initialize ports

Initialize timers and pwm channels

Initialize interrupt pins

While loop

{ check difference b/w current position and desired position variable for each position and run actuators accordingly

}

Interrupt routine 1

{ check other pin of encoder

If high then ++ for current position variable

If low then – for current position variable}

Interrupt routine 2

{ check other pin of encoder

If high then ++ for current position variable

If low then – for current position variable}

Interrupt routine 3

{ check other pin of encoder

If high then ++ for current position variable

If low then – for current position variable}

Interrupt routine

{ check combination of input ports and change desired position variables accordingly

}

Actual Code

```
#include <avr/io.h>

#include <avr/interrupt.h>

#include <util/delay.h>
```

```
int M2_DP=30, M4_DP=30, M6_DP=10, M3_DP=0, M2_CP=0, M4_CP=0, M6_CP=0,
M3_CP=0;


int main(void)
{   DDRD = 0b01101001;
        DDRB = 0b00000101;
        DDRC = 0b01000010;
        TCCR0A = 0b10100011; // fast pwm 8 Bit, Clear OCA0/OCB0 on Compare
Match, Set on bottom
        TCCR0B = 0b00000001; // Used no Prescaler
        OCR0A = 128;
        TCNT0 = 0;
        TCCR1A = 0b11000010;
        TCCR1B = 0b00010010;
        ICR1 = 1250;
        OCR1A = 1156;
        TCCR2A = 0b10000011;
        TCCR2B = 0b00000101;
        OCR2A = 23;
        EIMSK |= _BV(INT0);  //Enable INT0
        EICRA |= _BV(ISC01);
```

```
	EICRA |= _BV(ISC00); //Trigger on rising edge of INT0
	sei();
	PCICR |= _BV(PCIE2);
	PCICR |= _BV(PCIE1);
	PCICR |= _BV(PCIE0);
PCMSK2 |= _BV(PCINT20);
	PCMSK1 |= _BV(PCINT13);
	PCMSK0 |= _BV(PCINT5);
	TCNT1 = 0;
	DDRB |= _BV(PB1);
	TCNT2 = 0;
DDRB |= _BV(PB3);


	while(1)
{
if (M2_CP>(M2_DP+2))
	{
		PORTD &= ~_BV(PD5);
		PORTB |= _BV(PB0);
```

```
}
if(M2_CP<(M2_DP-2))
{
        PORTD |= _BV(PD5);
        PORTB &= ~_BV(PB0);
}
if(M2_CP>(M2_DP-2) & M2_CP<(M2_DP+2))
{
        PORTD &= ~_BV(PD5);
        PORTB &= ~_BV(PB0);

}
if (M4_CP>(M4_DP+2))
{
        PORTB &= ~_BV(PB2);
        PORTB |= _BV(PB4);
}
if(M4_CP<(M4_DP-2))
{
```

```
        PORTB |= _BV(PB2);

        PORTB &= ~_BV(PB4);

}

if(M4_CP>(M4_DP-2) & M4_CP<(M4_DP+2))

{

        PORTB &= ~_BV(PB4);

        PORTB &= ~_BV(PB2);


}

if (M6_CP>(M6_DP+2))

{


        DDRD &= ~_BV(PD6);

        PORTC |= _BV(PC1);

}

if(M6_CP<(M6_DP-2))

{

        DDRD |= _BV(PD6);

        PORTC &= ~_BV(PC1);

}
```

```
	if(M6_CP>(M6_DP-2) & M6_CP<(M6_DP+2))
	{
		PORTC &= ~_BV(PC1);
		DDRD &= ~_BV(PD6);

	}

	}
}
	ISR(SIG_INTERRUPT0) //Trigger on rising edge of INT0
	{
		if(bit_is_clear(PIND,1))
		{
			M2_CP++;
		}
		if(bit_is_set(PIND,1))
		{
			M2_CP--;
		}
	}
```

```
ISR(SIG_PIN_CHANGE1)
{
	if(bit_is_set(PINC,5))
	{
	if(bit_is_clear(PIND,0))
	{
		M4_CP++;


	}
	if(bit_is_set(PIND,0))
	{
		M4_CP--;


	}
	}
}
ISR(SIG_PIN_CHANGE2)
{
	if(bit_is_set(PIND,4))
	{
```

```
                if(bit_is_clear(PIND,7))
                {
                        M6_CP--;
                }
                if(bit_is_set(PIND,7))
                {
                        M6_CP++;
                }
                }
        }
        ISR(SIG_PIN_CHANGE0)
        {
                 _delay_ms(2000);
                if(bit_is_clear(PINC,0) & bit_is_clear(PINC,2) & bit_is_clear(PINC,3)
& bit_is_clear(PINC,4))
                {


                        M2_DP=30;
                        M4_DP=30;
                        M6_DP=0;
```

```
                }
                if(bit_is_set(PINC,0) & bit_is_clear(PINC,2) & bit_is_clear(PINC,3) &
bit_is_clear(PINC,4))
                {
                        M2_DP=30;
                        M4_DP=30;
                        M6_DP=10;
                }
        }
```

CONCLUSION & DISCUSSION

Different postures of the mannequin were achieved through simple buttons. We expect this project to be implemented in real times garment market to achieve goeals of this project. Implementation of this project will not only enhance and groom the marketing in a single dimension, but an attitude of use of technology will be introduced among garment industry stakeholders with practle example. Moreover a trend of designing new ideas in all aspects of businesses will grow in Pakistan, specialy those which involve technology.

This project if taken to market will be seen as new technique to enhace customer flow in a shop. By increasing flow it can turn out to be a very profitable product for garment shopkeepers.

Application of this project not only assist garments shops, but is helpful in fasshion show and exhibiton. This project if further groomed and modified can also be installed in many other fields like warning sign for public, traffic diversions and pysical training demonstrators.

With successful completion of this project we hope that this project will be used in real tmes business. Ameen.

REFERANCE

1. S. Bahadur & Y. Zheng, {1990}, Mechanical and tribological behavior of polyester reinforced with short glass fibers, Wear 137 (1990), p 7