DESIGN AND ANALYSIS OF WHEELCHAIR-MOUNTED MECHANICAL ARM USING CATIA V5

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Abstract: - A wheelchair-mounted mechanical arm (WMMA) is designed and built to assist individuals those are severely physically disabled and for elderly people for doing tasks in their daily life. The principle objective is to give techniques to finish important activities using a wheelchair-mounted mechanical arm for manipulation. Additionally, tasks which can be done by the arm are "Holding water glass or bottle", "Opening doors", "Flipping a light switch" and "Turning pages of the book". Major design considerations of the WMMA are cost, payload capacity, storage, and accessibility. The strength and deflection of critical parts of a robotic arm are tested through Finite Element Analysis (FEA) and the movement of the robotic arm is studied using Kinematics Analysis.
In this paper, we will come upon the following aspects:

- ***Study the static and dynamic parameters of the framework of the arm.***
- ***Look for the parameters by design and analysis of structure.***
- ***Study of the parameters influencing its performance.***

1. INTRODUCTION

1.1 Motivation

Assistive technologies systems are one of the exceptionally dynamic fields of present-day robotic research. In the previous few years, the interest in high-performance robots for everyday human activities expanded quickly because of the advancement of robotic technology. New robot technologies, acting as a team with people, can increase both productivity and quality of life. One such innovation is WMMA. A wheelchair-mounted mechanical arm can increase the capabilities of the physically impaired individual and elderly who are unable to do activities of daily life by themselves. Internationally around 785-795 million people aged 15 years and more are living with a disability based on 2010 population estimates. Of these, the World Health Survey estimates that 110 million individuals (2.2%) have exceptionally high challenges in working. Data from the NSO survey report of 2018, showed that the overall percentage of Indians with a handicap in the population was 2.2% from July 2018 to December 2018 in India. In 2009, a study estimated that over 5.5 million individuals in the US alone struggled with some sort of paralysis, with over 60% paralyzed to some degree starting from the neck. Indeed, more than 69% of all paralysis is a consequence of stroke, spinal cord injuries, and multiple sclerosis. This number is being increased every year rapidly, more people are becoming disabled and are unable to use their upper extremities. Rehabilitation Engineering and Robotics is used to improve the quality of life by growing independence and reducing the costs for assistance needed by the individual.

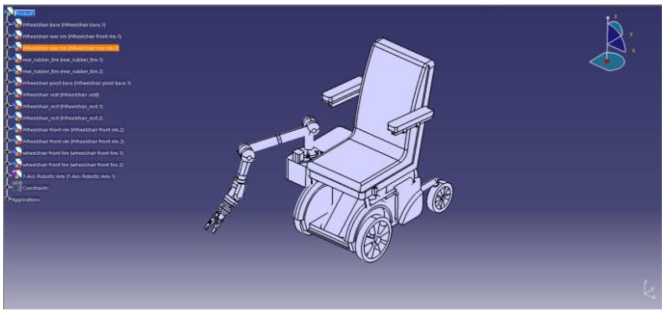

Fig 1. Wheelchair mounted mechanical arm design using CATIA V5R21

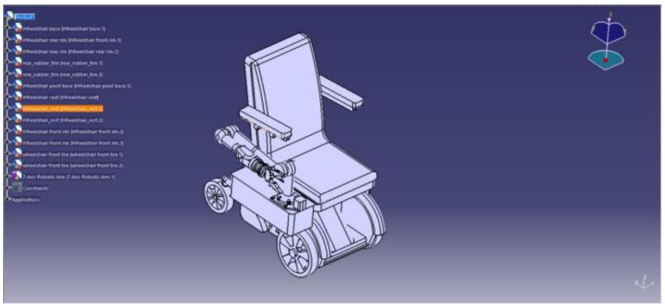

Fig. 2 Wheelchair with folded mechanical arm in CATIA V5R21

The focus of this innovation is primarily on the individuals who have limited or no upper extremity mobility. In the case of spinal injury or dysfunction, robotic aids are generally suitable for individuals with spinal deficiencies ranging from cervical spine vertebra 3 through cervical spine vertebra 5. Below the cervical spine vertebra 5, individuals often can be presented with easier, more conventional assistive technology. Persons with these injuries can generally utilize their upper limbs, and robotic arms are not required, nor significantly improve quality of life. Likewise, individuals with spinal fractures above cervical spine vertebra 3 are additionally not served well by robotic assistance. Otherwise, people with neuromuscular deficiencies such as multiple sclerosis can also take aid from these arms. People with varying level of impairment can utilize the WMMA. Users of this innovation are unable to do activities of everyday life so the wheelchairs are provided with a controller which controls the mechanical arm. Of the assistive robotic arms which are presently commercially accessible, 3 of the most notable are the MANUS, RAPTOR, and JACO arms. MANUS and JACO are seven degree of freedom (DOF) arms while RAPTOR is a four degrees of freedom (DOF) arm and two-fingered gripper for manipulation.

1.2 Background

A mechanical arm is a machine that imitates the action of a human arm. These are made out of various shafts connected by hinges controlled by actuators. One end of the arm is joined to a firm base while the other has an end effector or gripper. A computer-controlled mechanical arm is called is a robotic arm. Scientists have categorized the robotic arms by showing their industrial application, medical application, and technology, etc. First, it was introduced in late 1930 by William Pollard and Harold A. Roseland, where they developed a sprayer that had 5 DOF and an electric control system. Their technology was known as the “first position controlling apparatus”. Other mechanical arms were developed in 1961 by Unimate, evolving to the PUMA arm.

In the domain of assistive technology, robot arms have been utilized for rehabilitation and as workstations. Fixed-point gadgets enable some critically disabled people to acquire employments, eat and perform specific tasks. Various attempts were made over the years to make robotic assistants for people with various degrees of impairment. An early effort was made at the Case Institute of Technology during the 1960s. Rancho Los Amigos Hospital in Downy, California (Reswick 1990) was firstly attempted at rehabilitation robotics which included the Rancho “Golden” arm, designed in 1969. A powered wheelchair was mounted to an electrically driven 6 DOF robotic arm. The University of Pittsburgh’s Human Engineering Research Laboratories assessed the results of a Raptor arm on the independence of 12 critically impaired individuals. Remarkable improvements were shown in 7 of 16 activities of daily life (ADL) which included pouring or drinking liquids, picking up straws or keys, accessing telephones and refrigerators, and putting down a can on a low surface.

However, there were 9 ADLs, including making toast, which showed no significant improvement.

1.3 Objectives

The main purpose of this paper is to design, build and analyze the WMMA. In addition, the assistant robotic arm should be light-weighted, accurate, cost-efficient and the arm should be able to carry a 4kg payload at full reach. In this thesis, issues related to the strength of the mechanical arm and the movement of the arm are explored concerning the wheelchair and the person’s requirements. The design of the wheelchair and the robotic arm is done using CATIA V5 software. The design is done in such a way that there will be no damage to the wheelchair, the arms, and the gripper of the mechanical arm. The arms and wheelchair are designed individually and assembled afterward.

2. METHODOLOGY

CATIA V5

CATIA (Computer Aided 3-Dimensional Interactive Application) is a multi-platform software suite for Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), Computer-Aided Engineering (CAE), PLM, and 3D, developed by the French company Dassault Systèmes. CATIA started as an in-house development in 1977 by French aircraft manufacturer Avions Marcel Dassault to provide 3d surface modeling and a Mirage fighter jet was developed at that time using NC functions for CAD/CAM software. Later on, it was used in aerospace, automotive, shipbuilding, and other industries.

CATIA helps in designing 3D parts, from 3D sketches, sheet metal, composites, molded, forged, or tooling parts to the importance of mechanical assemblies. The software provides trend technologies for mechanical surfacing and part design. It gives tools to finish product definition, including functional tolerances as well as kinematics definition. CATIA provides a broad scope of uses for tooling design, for both generic tooling and mold & die. CATIA also assists multiple stages of product design whether started from scratch or 2D sketches.

2.1 Mechanical Design

To understand thoroughly what parameters the arm needed to be designed for, plenty of of researches were conducted based on the correction of the design of the mechanical arm. Various criteria were taken into consideration, such as

- Low cost of the whole structure (under $5,000)
- Relatively high payload capacity (Capacity to lift and hold the load of 4kg object)
- Excellent maneuverability (fold-able and extendable up to 1m)
- Compact storage (arm able to be stored on side of the wheelchair), and
- Lightweight. (under 5 kg weight)

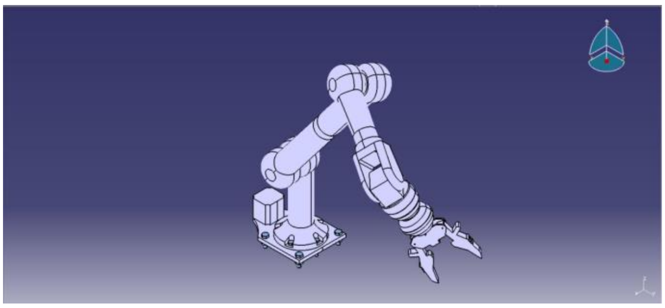

Fig. 2 Design of 7 Axis Mechanical Arm in CATIA V5R21

Low Cost of the structure:

Cost is the greatest factor keeping an average household from buying a robotic arm that would improve the quality of life.

The weight-age of about 30% is given to the cost in this list. Most robotic arms in the market are $20,000+. So, to satisfy the low-cost requirement of the design, a new design has to be made so that the cost can be reduced below $5,000 and even people with average income can also be able to buy this product.

Relatively high payload capacity:

Low payload capacity is a serious issue for those who are having problems doing their everyday activities. That is why payload capacity is given the weight-age of around 25% in the list. The design should be able to extend the arm and be able to hold the load of 4kg at the same time. Considering the weight of the majority of the average things in the grocery store and home WMMA is designed with a payload of 4kg.

Excellent maneuverability:
The robotic arm is attached to the wheelchair at the sides of the chair because it helps with the balance of the chair. Maneuverability is given the weightage of 20%. However, it should be taken care of to prevent the widening of the wheelchair. The mounting position allows the arm to be packed by folding it back and covering the gripper under the seat.

Storage and Weight:

These storage and weight criteria are also very important based on of making the design but they are given the weightage of 15% and 10% respectively and this is because the priority is to design for ease of use.

The mechanical arm is designed to have 7 degrees of freedom. The joints used in this arm are revolute joints which are chosen over prismatic and some other types of joints because of their packaging efficiency and mechanical simplicity. The adjacent joints are oriented at 90 degrees throughout the arm.

PARTS OF THE MECHANICAL ARM

There are a lot of parts that are used in making a robotic arm. But there are some basic parts with which it is impossible for a robotic arm to do its job and those are:

- Controllers
- Arms
- End Effector
- Drives
- Sensors

CONTROLLERS:

Controllers, also known as Regulators, are the main processors of the mechanical arms and act as their brains. They can either act automatically as programmed or allow for manual operation by outputting instructions directly from a professional. They are the control center of the mechanical arms and come in a mixture of styles as indicated by what sort of processing power is required.

ARMS:

The arm is the main segment of the mechanical arm and comprises three sections: the shoulder, elbow, and wrist. These are altogether joints, with the shoulder resting at the foundation of the arm, ordinarily associated with the controller, and it can push forward, backward, or spin. The elbow is in the center and permits the upper part of the arm to move forward or backward independently of the lower part. At last, the wrist is at the end of the upper arm and connects to the gripper (end effector).

END EFFECTOR (GRIPPER):

The gripper acts as the hand of the mechanical arm. It is normally made out of two claws, though sometimes three, that can open or close on order. It can also turn on the wrist, making moving material and gear simple.

DRIVES:

Drives are the engines in the middle of the joints that control the movement and moves. They commonly use belts like found in car engines.

SENSORS:

Sensors are more frequently found in advanced robots. Some are filled with sensors that permit them to detect their environment and respond according to that. For instance, they stop crashes between two robots who might be working nearby or permit the robot to change its grip on a fragile object to prevent damaging it.

2.2 Analysis

Analysis of the WMMA in everyday tasks

Mechanical arm required for daily tasks

In this paper, it is shown that the following factors should be considered while defining the tasks of robotic arms.

1. Operability
2. Priority
3. Uniqueness

Activities of daily life for Mechanical Arm

According to the above section, requirements should be considered under the activities of daily life. There are multiple activities which are needed to be done daily and due to their disabilities, people are unable to do any tasks by themselves and rely on any human assistance. But in this paper, a few amounts of tasks are being considered such as Task 1 includes the holding of different objects in various environments. The subjects which are used in this experiment are of different shapes and sizes and also have different loads added to them. The mechanical arm is seen that whether it can perform tasks efficiently or not and if they maintain steady motion while performing the tasks.

S. No.	Tasks	Related	Requirements
1	Holding Objects	Shapes / Sizes of the Objects	Stationary
2	Eating / Drinking	Users	Security
3	Opening the door / Drawing	Shapes / Sizes of the Objects	Accuracy
4	Pressing the button	Shapes / Sizes of the Objects	Accuracy
5	Wiping Shaving or Doing Make Up	Users	Security

Table No. 1

Task 2 and Task 5 are tasks related to the person who is using the product themselves. The main needs of these tasks are to make sure whether the user is safe and steady movement. Task 3 and Task 4 are related to the shapes and sizes of the objects in the environment. Accuracy is required by the robotic arm to meet the constraints of the surrounding.

Classification of the daily tasks

Based on the above analysis, this paper is classified into three important categories and are Task 1, which are related to "free objects". In Task 1, there are objects which can move freely in more than one direction. In Task 2, these are related to the "structured environment". In this task, objects can move in a specific direction. In Task 3, it is related to the "user themselves". These tasks have a close link with the person using the product themselves. The tasks are classified visually in the table below (Table No. 2). The typical tasks of Task 1, Task 2, Task 3 are "holding water glass", "Opening door", and "Eating" respectively.

Classification Rules	Characteristic	Related Tasks	Typical Tasks
Free Objects	Objects can move freely in more than one direction	Grasping Objects	Holding water glass
Structured Environment	Motion of objects are constrained	Opening Door / Drawer, pressing the button	Eating
Users Themselves	Safety and stability are required in motion	Eating / Drinking, Personal Care	Eating

Table No. 2

To see how the mechanical arm configuration would respond or work under particular conditions, it was significant that some exploratory calculation occurred to discover that no issues would emerge further in the plan interaction. Of the 7 DOFs, half of them ($\theta 3$ - $\theta 5$) are contained inside the arm itself. $\Theta 1$ is the result of a joint between two segments of the wheelchair, while $\theta 2$ is a result of a connection between wheelchair mount and the foundation of a mechanical arm. $\Theta 6$ will be added at the joint between the gripper and the third connection in the mechanical arm. A worst-case static analysis was performed where a worst outcome imaginable was considered in which the payload was gotten a handle in the end effector toward the finish of the flat, outstretched arm. Each joint was separately tried for the maximum load it could lift. This was finished by placing the arm in a posture generally unfavorable for the joint being referred to. For instance, the arm was set completely outstretched, pointing forward corresponding with the ground. Loads were logically added, and the joint was given full ability to attempt to raise the loads.

Stress Analysis of Mechanical Arm

The Finite Element Analysis method acquired its main importance in the year 1960s and 1970s. The method was developed from the demand to resolve the complex elasticity and structural analysis problems in aeronautical, civil, and mechanical engineering. FEA analysis was done on the overall assembly design using CATIA V5 software from which it was found that the arm was able to withstand the load more than 4kg (approximately 10kg). The base of the arm is held fixed using the Clamp command in CATIA during the analysis. Four node linear tetrahedral elements are used in the mesh: Mesh Type: Solid Mesh, Total no. of nodes: 10153, Total no. Of Elements: 38488. The arm is analyzed using three materials and those are SILVER, ALUMINIUM, and IRON. The FEA result shows that the Von Mises stress is used for the analysis of the arm.

Material	: Aluminium
Young's Modulus	: 7e+010 N m^2
Poisson's Ratio	: 0.346
Density	: 2.71 g cm^3
Coefficient of thermal expansion	: 2.36e-005 K deg
Yield strength	: 9.5e+007 N m^2

Table No. 1 Properties of Aluminium

Material	: Iron
Young's Modulus	: 2.11e+011 Nm^2
Poisson's Ratio	: 0.291
Density	: 7.87 gcm^3
Coefficient of thermal expansion	: 1.21e-005 K deg
Yield Strength	: 3.1e+008 Nm^2

Table No. 2 Properties of Iron

Material	: Steel
Young's Modulus	: 2e+011 N m^2
Poisson's Ratio	: 0.266
Density	: 7.86 g cm^3
Coefficient of thermal expansion	: 1.17e-005 K deg
Yield Strength	: 2.5e+008 N m^2

Table No. 3 Properties of Steel

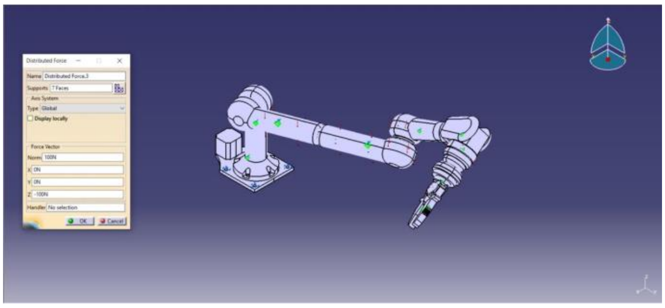

Fig. 3 Force applied 40N

Force applied on the arm is 40N and 100N (as shown in Fig. 3 and Fig. 4 respectively).

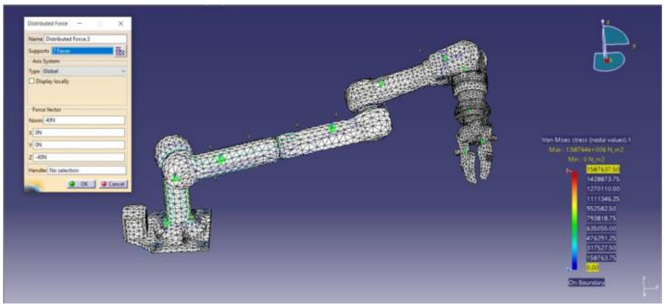

Fig. 4 Force Applied 100N

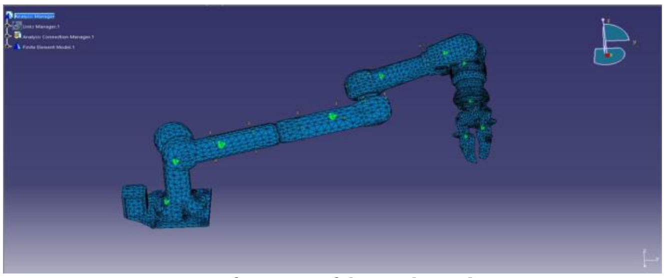

Fig. 3 Deformation of the Mechanical Arm

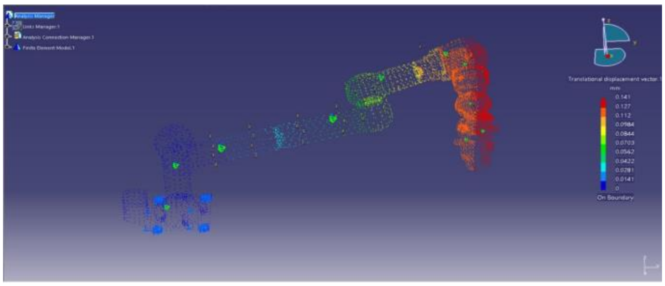

Fig. 5 Displacement of Mechanical Arm under practical weight (40N)

The displacement vector when the load applied on the arm is 40N is 0.141mm whereas the displacement vector is 0.325 when the load is 100N.

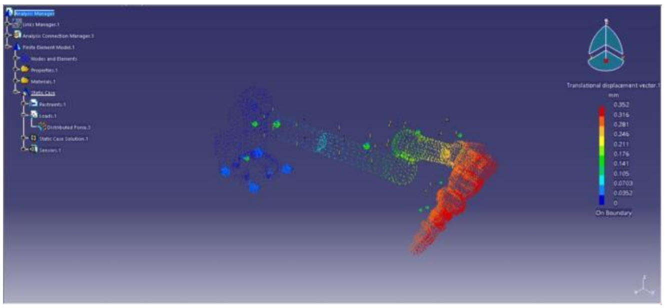

Fig. 6 Displacement of Mechanical Arm under load (100N)

The maximum stress and minimum stress are observed with the help of the Von Mises stress and the Maximum stress and Minimum stress on the arm when the load of 40N is applied are 1.58764e+006 Nm^2 and 0 Nm^2 respectively (shown in Fig. 7).

Maximum stress: 1.58764e+006 Nm^2
Minimum stress: 0 Nm^2

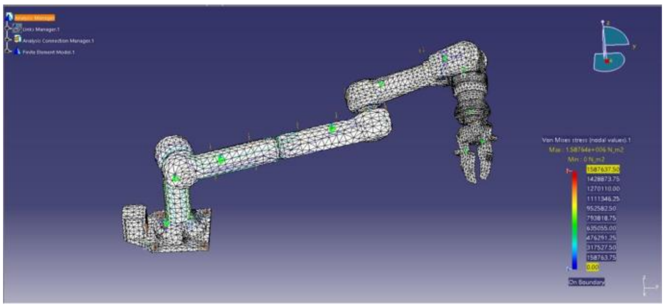

Fig. 7 Von Mises Stress (Nodal Value - 40N)

And the maximum and minimum stress for load of 100N are 3.96909e+006 Nm^2 and 0 Nm^2 respectively (in Fig. 8).

Maximum stress: 3.96909e+006 Nm^2
Minimum stress: 0 Nm^2

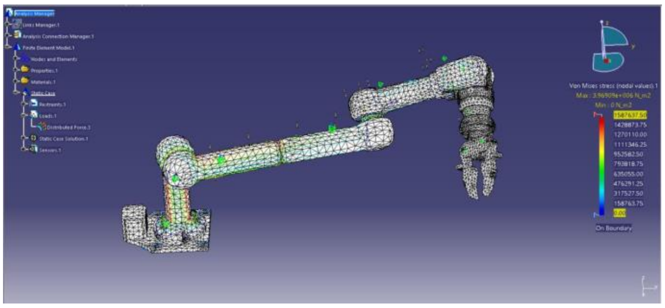

Fig. 8 Von Mises Stress (Nodal Value - 100N)

3. CONCLUSION

Physically disabled people who have to be dependent on some other human assistance are independent with the help of the Wheelchair mounted mechanical arm. The designed WMMA is cost-efficient, can pick a load of more than 4kg (around 10kg), and is also able to extent properly without any resistance. With the help of Finite Element Analysis and

Kinematic Analysis the strength and mobility of the arm if observed. It is also observed that the deflection of the end effector is approximately 25mm when fully loaded with weight. Considering the weight of many of the home supplies the WMMA was made with a payload of approximately 4-5 kg.

We think that this design will outperform former attempts made at building wheelchair-mounted mechanical arms that are truly helpful and advantageous.

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