Research Article
Kinematic and Kinetic Study of Rescue Robot by SolidWorks Software

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Abstract: In this study, the studied software as the Product Data Management (PDM) provides solutions for helping to control designing data. Users can be sure of storing their own designing data for quick retrieval of data and reducing the concerns about control of edited data and losing data and even sharing and collaborating in online projects with members of local networks. If the designers want to change their way in analyzing every component of mechanical mechanism, the selected component should be studied for the Finite Element Analysis (FEA) in order to be analyzed structurally. Finite element analysis is a numerical method for structural analysis and leads to the dominant approach of "Computer Aided Engineering" (CAE) for study of structure. Finite element analysis can evaluate a variety of motion, component analysis, stresses and vibrations from the under-load static and dynamic bracket. As the result of motion simulation, the input data, necessary for the structural analysis done by FEA, is provided. Providing the simulation and study of integrated and simultaneous motion is among the features of software SolidWorks. By this feature of Software SolidWorks, the designers will be able to reduce the number of required pilots. This study provides the suggestions for development of designing and working in the field of building the rescue robots for relevant organizations.

Keywords: CAD, FEA, rescue robot

INTRODUCTION

Kinematic and kinetic designing process of rescue robot is created by fulfilling a set of limitations which are resulted from the nature laws. In the case of robotic design, these laws are obtained from the Kinematic and dynamic equations and a set of desired properties. Others constraints are resulted from the technological limitations, but modeling is more complex in them. Rescue robot is a robot, which is designed for helping to rescue the workers and people who have been exposed to the natural and work disasters. The conditions, which are related to the act of and rescue robot, include the mining accidents, natural and urban disasters, hostage situations and explosion.

Some related studies are presented about progress in Robot sysytems. The sensitivity analysis with respect to design parameters is carried out to provide an insight to their effects on the performance criterion under kinematic constraints (Dongmok *et al*., 2012).

In some cases SolidWorks is used for solid modeling and assembly, CosmosMotion is used for rigid body dynamics, CosmosWorks is used for finite element vibration and strength analyses and Adlink module is used for actuator control (Akdağ *et al*., 2012).

Also modeling of L-MCRS has been tackled from geometrical and dynamical points of view. Echegoyen showed that the passive element is modeled by splines and the dynamical modeling is achieved by the appropriate extension of Geometrically Exact Dynamic Splines (GEDS). The system's modeling allows realistic simulation, which can be used as a test bed for the evaluation of control strategies (Echegoyen *et al*., 2010).

Advantages of rescue robots include the reduced required personnel, reduced fatigue and access to the inaccessible and in general reduced human risks for survivors and saviors through increasing the capabilities and accuracy of rescue robots. Since the increased capabilities of rescue robots in designing and innovating is summarized in the field of manufacturing them, in this study the author has focused on the kinetic and kinematic study through introducing the advantages and features of software SolidWorks.

One of the common methods of designing is to use the similarities existing in the function of artificial or naturalorgan. In a multi-dimensional matrix space (R^{m*n}) the design is described based on the relations between the attached and detached parts. By establishing an appropriate correlation among the objects and the proper definition of the relationship among them, a successful design can be depicted similar to a successful design in the space. Observing and evaluating the biological manipulators induct the similar structures which are used in designing the robots. Tendons and muscles create several closed chains in the natural environment. While the overall

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structure of biological manipulator is an open and a defined space. The volume of work space in this kind of set can be wide in terms of access to the motionangles. A kind of series to parallel conversion can be seen in the hybrid structures. This can be seen in human movement, so that while moving, this conversion is done with each step. For movement, the conditions of contact with the ground should be changed or the foot be replaced.

Natural organs are seen as two species of internal and external skeleton. The main designs in the robotic structure have analyzed the motion of exoskeleton. Meanwhile, the muscles, tendons, bones and joints are mentioned as the Anatomic elements at the macroscopic scale. The origin of simulation in the robotic structure contains the mechanical actions of expansion, contraction and motion of these elements. Common designs of manipulators have been based on the method of arms and joints series. Series robots have problems such as error, low rigidity and high unsteadiness in the attached parts. However, since their model has been fully investigated and studied, it is used in most of the plans. The large metal structures are used mainly in these robots and their wide work space is the main advantage of these kinds of robots. Since the natural organs have also the series and parallel structure, a combination of these two will be appropriate. Rescue robots, Software SolidWorks are presented in this study. At the end of study in conclusion part all datas about Kinetic and kinematic study of Rescue robots by software SolidWorks Wraped-up.

RESEARCH METHOD

Programming in the software environment SolidWorks is used for modeling the environment of experiment. Different types of series and parallel motion can be defined for different parts of robot in this software. This software is run under Windows environment.

Issue expression: Parallel Mechanisms include the closed kinematic chains by which the final operator is connected to the basis. The main motivation in using these kinds of mechanisms has been to compensate the common series structures such as low accuracy, error accumulation, low hardness and low power of carrying the load. Numerous advantages of these mechanisms reduce their main defects which are the limitation of work space and existence of different singular modes; particularly the advantages of both series and parallel structures are used in the designing by applying the hybrid structures. Parallel structures are usually much lighter and smaller than the series samples. Redundancy is another more important feature which we are faced with in investigating such a structure.

In general, dynamic of parallel mechanisms with stimulation redundancy is so complex due to the numerous constraints and there is a few research conducted in this regard. However, evaluating the common methods in obtaining the dynamic equations in robots and generalizing them to the hydraulic structure as a parallel structure with stimulation redundancy determine the details of each methodclearly andreveal the advantages and disadvantages of each one.

Theoretical principles: The singular modes should be inevitably considered in the Kinematic study of mechanical systems. These modes are defined in corresponding with the Jacobian Matrix of Mechanism which determines the correlation between the input and output speed. The issue of Static is so important in determining the correlation of forces and moment in the balance state and as we know it is associated with Jacobian Matrix of Mechanism. Since the degree of freedom in each mechanism is changed immediately in singular states, these states are usually undesirable and evaluating them is so important. The research conducted by Ma and Angeles (1991) and Gosselin and Angeles (1990) are among the various studies which have been evaluated and calculated the singular states in different mechanisms.

Not only all mechanisms are singular within their own work space, but also they may include these singular points inside the Sp work space. In the series mechanisms, the singular state occurred when the axis of rotary joints are in a direction. However, this is not true for the spherical joints. In these conditions, the robot is locked in some of the movements because the degree of freedom is reduced. In the series mechanisms, the free motion is equivalent to the motion of manipulators, in such a way that the position of final operator is not changed. It is possible to exit from the singular state by such a motion in a specific mechanism. In parallel robots, the singular states have been classified based on their specific type. If the kinematic limitations are shown as a nonlinear function of joint variables (q) and the position in the Cartesian space (x), we will have F (x, q) = 0. It can be written based on derivative of this function in terms of time that:

$$Ax * + Bq * = 0$$
$$A = J_x = \delta F/\delta q, A = A (x, q)$$
$$B = J_q = \delta F/\delta q, B = B (x, q)$$

Merlet (1992) singular states have been classified in corresponding with the rank deficiency of matrices Jq, Jx or both. So that the rank deficiency of Jx is called direct kinematic singularity and the rank deficiency of Jq called the reverse kinematic singularity. In the cased that both of the matrices Jq and Jx have the rank deficiency, we will have a specific singularity called the

structural singularity or the unstable type. This type of singularity occurs in the robots with specific kinematic structure and it should be prevented at the stage of designing the mechanism. In this state, controlling or the strategies of preventing from the singularity is so difficult. In such a state, the mechanism can have limited movements despite locking the stimuli. In fact, the limited motion in input will not lead to the motion in output. In other words, it is not possible to balance the load on the movable plate and this is so important based on the designing.

Reverse kinematic singularity occurs when each of the limbs is completely open or folded; or in other words, when the kinematic chain is reached the border of work space or an internal border. Then ullity of Jq isnon-zero in this case. Therefore, the non-zero vectors of $\dot{q}$ can be found, so that $\dot{x}$ becomes zero. It means that the specific speeds (perpendicular to border) cannot be produced in output. Output manipulator in this state loses one or more degrees of freedom. But direct kinematics singularity exists inside the work space of chain and should be removed. In this state, the movable plate can have the local free motion despite the fact that all stimulated joints are locked. In this case, the nullity of Jx is non-zero, thus there are the non-zero speeds in the output of ($\dot{X}$) and they are mapped onto the source; in other words, their corresponding speeds in the input ($\dot{Q}$) are zero. Output manipulator gains one or more degrees of freedom in this state. Generally, according to the equation Ax*+Bq* = 0 it can be written for a parallel mechanism with six degrees of freedom that:

$$q^* = -B^{-1}Ax^*$$
$$x^* = -A^{-1}Bq^*$$

In which, Matrix A depends largely on the specifications of dependent structure, while Matrix B depends on the joint variables. Therefore, reversing the B is not difficult, unless the length of one of the manipulator is zero which does not happen practically. However, reversing A is so difficult. Thus, it can be concluded that the reverse kinematic can be simply calculated in these kinds of mechanisms, while the direct kinematic is more complex. Therefore, if we define the Jacobian of mechanism as the linear conversion from the joint space to the Cartesian space, we will have J=A^{-1} B which is never appropriate for the analysis because it includes the reverse matrix A and in the case that A is specific, Jacobian cannot be defined. Therefore, Jacobian of parallel mechanisms is defined as the reverse map from Cartesian to the joint space. In these conditions we will have J = B $^{-1}$A.

RESCUE ROBOTS

Rescue robots are built in order to find and identify the injured individuals and identify the reliable ways to send the essential materials for surviving the injured ones. These robots have the following capabilities as follows:

- They can easily move inside the ruins and debris
- They can find the injured individuals and report their vital signs
- They can provide the possibility to communicate with the rescuers
- They can prepare the map of environment and its details
- They can identify the places in where there is the possibility of debris falling
- They determine the safe routes for the rescuers' activity and determine the best way to rescue the injured individuals and generally help the rescuers to find the injured individuals quickly and rescue them

Different parts of rescue robot are classified into three main sections.

- **Software:** A program which is written for doing the motion by robot processor.
- **Hardware:** (Electrical)- It includes the designed and performed electronic circuits. Hardware is classified into three general categories of sensors, processors and driving force.

○ **Sensor:** The sensor is a sense element which converts the physical quantities such as pressure, temperature, humidity, temperature and… into the electrical continuous (analog) or discontinuous (digital) quantities. Sensors are often used for understanding the contact, tension, proximity, visual and audio information. Based on the performance of sensors, they create the small voltage levels in response according to the factor changes, which are sensitive to them and the received information can be interpreted by processing these electric signals and be used for further decision making.

○ **Processor:** Information processing in the robots is as the performance of human brain. The information, which comes to the processing unit from different parts, is processed in this section and the commands and drivers become available for them. Based on the type of robot, the appropriate processing system, which can include the Programmable Logic Controllers (PLC), Micro process control systems and industrial computers, is used.

○ **Driving force:** It is a system which provides the necessary energy for robot motion. Robot motion not only depends on the driving force, but also on the design of mobility (wheels). Wheels are classified into the types such as Tank system and powerful legs (with different types of electric

motors, dc motors, Stepper motors and servo motors), hydraulic wheels, pneumatic wheels or air muscles. Before selecting the motor, the required power of each motor should be determined. For motion of robot, two forces of Friction and gravity should be overcome. By joining each of these two forces the equation required to move the robot is obtained.

MECHANICAL

In this section, the tools, angles and motion limitations and the reaction of robot (Motor and manipulator) are designed and implemented.

SOFTWARE SOLIDWORKS

During the recent years, we have seen wide improvements in the field of design automation in the industrial software world. Software designers in mechanical engineering have optimally accelerated designing and achieving the ultimate goal by considering more and strong facilities for using these kinds of software. People had to pass the whole technical course for using this software in the past, but today the way for using this software can be learned and they can be used easily by spending the minimum time. SolidWorks is one of the leading software which fulfills almost all needs of a design engineer; this software is manufactured by a company with the same name and is currently the subset of Dassault System, the manufacturer of software CATIA. Undoubtedly, we can claim that SolidWorks is the strongest engineering software in two fields of RealTime and GUI. It has almost the same rank as CATIA and is absolutely superior to MDI for the mechanical engineers in technical designing world. Its *Help* has almost the extent and efficiency of MATLAB and easily connect to other software such as ANSYS, Visual NASTRAN, CATIA and EXCEL and, here, we review a few selected topics for more detailed study and familiarity with this software.

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SolidWorks is one of the leading software which fulfills almost all needs of a design engineer; this software is manufactured by a company with the same name, however it is currently the subset of Dassault

System, the manufacturer of software CATIA. Undoubtedly, we can claim that it is the strongest engineering software in two fields of RealTime and GUI. It has almost the same rank as CATIA and is absolutely superior to MDI for the mechanical engineers in technical designing world. Its *Help* has almost the extent and efficiency of *Help MATLAB* and easily connect to other software such as ANSYS, Visual NASTRAN, CATIA and EXCEL and, SolidWorks Corporation (2002) the software SolidWorks is designed for automation design which integrates the ideas and experience with each other in 3D models. This software has the ability to do the following cases.

- Designing and Manufacturing the parts
- Assembling different parts of robot
- 2 and 3-dimensional designing of parts and components
  Kinetic and kinematic study by software SolidWorks is presented as follows:

KINETIC AND KINEMATIC STUDY BY SOFTWARE SOLIDWORKS

Kinematic studies are a kind of motion simulation for the assembly models by the schematic models. In this software, the visual features (lighting, landscape angle and camera movement) have been embedded for the composition and simulation of motion. Through the kinematic study the motion and correlations of parts and components and the basic(preliminary) movements can be analyzed according to the mobility management by the animation tools. Working with this software is done schematically and by the help of mouse and all commands can be run through clicking on the corresponding icon on the screen of software in Windows environment. Therefore, the robot motion has no need for the commands of programming language. For instance, the function of named tools is described as follows:

- **Animation:** You can run the animation of set by the Move command and soliciting as follows.
- Add the driving force engine including one or more parts of assembled models to the main page of software or driver.
- Determine the position of assembled components in different times by using the key points. Animation defines the motion of assembled components among the key points by using the interpolation.
- **Basic movements:** You can take advantage of the basic movements in order to estimate the effects of motors, springs, contact and gravity in the
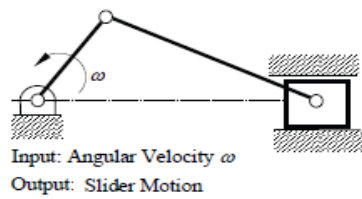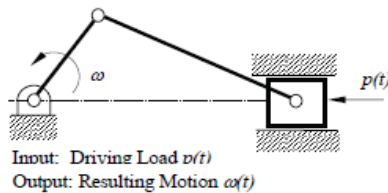
Fig. 1: Kinematic analysis

Fig. 2: Dynamic analysis

Fig. 3: System of mass, spring and damper

Fig. 4: Pendulous motion

assembly. The tool of basic movements considers the mass in calculating the motion. Calculating the basic movement is relatively quick, thus this tool can be used to create the animation by using the physical principles based on the simulation.

- **Kinematic motion analysis:** Users can use the motion analysis tool for creating the accuracy in the simulation and analyzing the effects of driving forces (including the forces, springs, shock absorber and friction) in the assembly. By using the strong calculators, the motion analysis tool performs the calculations of motion, material properties, mass and inertia in the kinematic analysis. You can also use the motion analysis tool by the technique of drawing the results through applying the simulation, of further study.

Kinematic motion study is defined without considering the moment forces. A Kinematic system can be led by adriving motor in a state in which the velocity and momentum analyze each of the connection of Kinematic system at any time. Figure 1 shows a motor with drives of Kinematic system with constant angular velocity.

Dynamic analysis for the study of motion mechanism in response to the loads of kinematic system is shown according to the Fig. 2. This is the most complex, common and usually the most time-consuming kinematic analysis.

Designing the motion of rescue robot is done based on the defined task for it. The main task in these kinds of robots is the function of sensors in finding the survivors and sending the rescue messages for the rescue forces. The important point in implementation of robot tasks is the designed motion power for the robot is according to different rescue environments and conditions (Temperature, obstacles, slope, fall of objects, etc). Based on the available level for the rescue
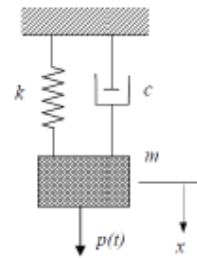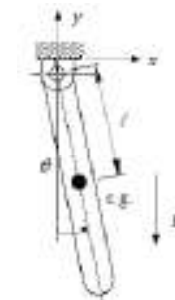
operation, different types of wheels of tank, hydraulic and pneumatic systems will be the solutions for mobility of rescue robots. Physics science should be applied for designing different types of robot wheels. For instance, two factors of pressure and pendulous motion will be analyzed according to the design as follows. Calculations show the elements which should be considered for a simple motion in designing the robot.

Pressure: Kuang-Hua (2012) dynamic analysis is provided for the study of motion in line with the external loads. Dynamic behavior of each performance of Newton's laws is used in motor design and computing. For instance, a system of mass, spring and damper is shown in Fig. 3. In this case, the motion is calculated by the following equation of Newton's second law and according to the mass force.

The equation derived from Newton's second law is $\Sigma F = p(t) - kx - c\,\dot{x} - m\,\ddot{x}$. In which (x) in high physical values represents the time derivative of quantities; m is the total mass of block; K the constant value of spring and C is the damping coefficient.

Pendulous motion: For a rigid body, the mass properties (such as mass, center of gravity, moment of inertia, etc) are calculated for dynamic analysis. For further expression, the pendulous motion, which is shown in Fig. 4, is calculated by the equation:

$$\Sigma M = -mg\,\ell\,\sin\theta = I\ddot{\theta} = M\,\ell\,2\ddot{\theta}$$

M is the external moment; I the mass moment of inertia; M the mass of pendulum, G the momentum of

gravity and eventually $\ddot{\theta}$ is the angular momentum of pendulum.

Software SolidWorks has the feature to design the robot from determining the task and robot performance and primary design to creating the experimental model (including determination of parts, assemble, weighting, connections, relations of components, sensors, communication and messaging, processor software and driving force). As mentioned, this software performs the design, calculation, simulation and experimental implementation of robot function and its different parts by the schematic command and in Windows environment. Some of the features of this software include:

- Controlling the balance program and degree of freedom of robot
- Controlling the balance of robot among the internal components such as the engines and static of robot in the operating environment
- Simulation of robot behavior of and its kinematic study
- Calculations of assembly and components in terms of mass, connections, required degree of freedom, consumed energy and necessary power in driving force of robot
- Improving the control algorithm at the final stage depending on the real environment of operation through the simulation of process.

CONCLUSION

Studied software in this study (SOLIDWORKS) provides solutions for helping to control the design data as the Product Data Management (PDM). The user can make sure of saving the design data for quick retrieval of data and reducing the concern about controlling the edited data and losing the data and even sharing and collaborating on online projects with the members of local networks. By options of SOLIDWORKS PDM, the team design way can be managed and the collaboration on designing can be improved. Installing, launching and applying the software SOLIDWORKS PDM is very easy and requires a little support of IT and can determine the workflow of users' project. Given the integration of design options in the software SOLIDWORKS, the design team can focus on the product and innovation development. Regardless of the size and expansion of organization, the users can develop the efficiency resulted from the product improvement process. Moreover, the software SOLIDWORKS has the solutions for data management (especially in the local networks) in large and small organizations.

In the process of performance simulation of mechanical structures, the structural designers need to determine the kinematic and dynamic structures of new

products or simulate before producing the physical pilots. Robotic motion simulation is a method for solving the basic problems in designing. Robotic motion simulation in the relevant software reduces the cost of initial construction of product (robot) significantly. Furthermore, by the visual analysis of functional primary mechanism in the software the product designers can convert the motion of synthesis mechanism into the geometrical circuit of motion in a three-dimensional simulation environment and use it for creating a new geometrical part.

After the simulated studies of motion, if the designers want to change their way in analyzing every component of mechanical mechanism, the selected component should be studied for the Finite Element Analysis (FEA) in order to be analyzed structurally. Finite element analysis is a numerical method for structural analysis and leads to the dominant approach of "Computer Aided Engineering" (CAE) for study of structure. Finite element analysis can evaluate a variety of motion, component analysis, stresses and vibrations from the under-load static and dynamic bracket. The result of motion simulation is to provide the input data necessary for the structural analysis done by FEA. Providing the simulation and study of integrated and simultaneous motion is among the features of software SOLIDWORKS. By this feature of Software SOLIDWORKS, the designers will be able to reduce the number of required pilots

SUGGESTION

- Designing the robot for Urban Search and Rescue (USAR) is a very challenging task, because it denies most of the robotic laboratory assumptions in practical environment (Jacoff *et al*., 2004). The international rescue RoboCup competition provides the opportunity for measuring the performance in real environments and allows the competitors to provide the possible opportunity for the review and assessment of hardware and software of new and developing technologies. It is suggested that the relevant domestic organizations of robotic design fix their own way of appropriation towards investigating in the field of designing different types of rescue robot. Given the natural domestic disasters, among which the earthquake is the most important one, designing and producing these kinds of robots is essential.
- Holding the student Olympiad in this regard will make the future and support the production of such these resuscitative products.
- By supporting the plans, which have been reached the stage of rescue production and experiment, the government provides the possibility for employment and exporting it to other applicant countries. On the other hand, the deficiencies of

designing and production will be also clear and lead to the promotion of rescue robots.

REFERENCES

Akdağ, M., H. Karagülle and L. Malgaca, 2012. An integrated approach for simulation of mechatronic systems applied to a hexapod robot. Math. Comput. Simul., 82(5): 818-835.

Dongmok, K., H. Heeseung, S.K. Hwa and K. Jongwon, 2012. Optimal design and kinetic analysis of a stair-climbing mobile robot with rocker-bogie mechanism. Mech. Mach. Theory, 50: 90-108.

Echegoyen, Z., I. Villaverde, R. Moreno, M. Graña and A. d'Anjou, 2010. Linked multi-component mobile robots: Modeling, simulation and control. Robot. Auton. Syst., 58(12): 1292-1305.

Gosselin, C. and J. Angeles, 1990. Singularity analysis of closed-loop kinematic chains. IEEE T. Robotic. Autom., 6(3): 281-290.

Jacoff, A., E. Messina and J. Evans, 2004. A standard test course for urban search and rescue robots. Proceedings of the Performance Metrics for Intelligent Systems Workshop.

Kuang-Hua, C., 2012. Motion Simulation and Mechanism Design with Solid Works Motion 2011. SDC Publications, Schroff Development Corporation, File No. 978-1-58503-669-1-1.

Ma, O. andJ. Angeles, 1991. Architecture singularities of platform manipulators. Proceeding of IEEE International Conference on Robotics and Automation. Sacramento, California, pp: 1542-1547.

Merlet, J.P., 1992. On the infinitesimal motion of a parallel manipulator in singular configurations. Proceeding of International Conference on Robotic and Automation. Nice, France, pp: 320-325.

SolidWorks Corporation, 2002. SolidWorks Student Workbook. Retrieved from: http://www.Solidworks.com/education., Document No: SWSWBENG0402.