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Kinematic analysis of cinema dolly

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Goal of the work

- To review mechanisms used in movie industry and explain their functions
- To produce 3D virtual model of a chosen mechanism
- Perform its kinematic analysis

Mechanisms in movie industry

- **Mechanisms inside movie-camera**: intermittent mechanism (fig.1), shutter mechanism etc.
- **Mechanisms inside the movie artefacts** – performs decorative and visual functions (fig.2).
- **Mechanisms in movie production** – typically robots, helps to make visual effects, but usually not visible in final product (fig.3).

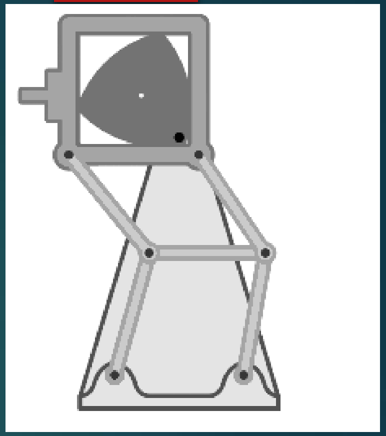


Fig.1

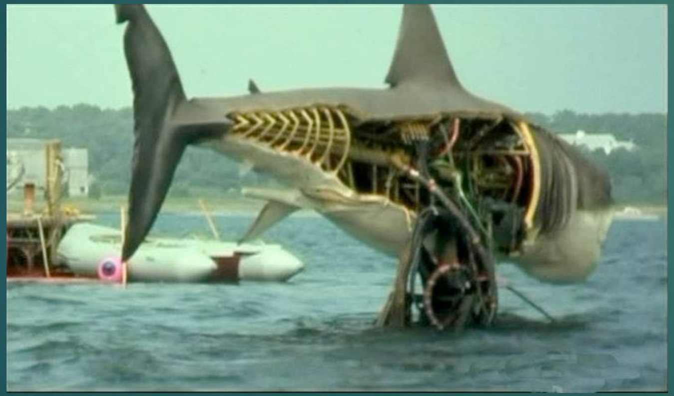


Fig.2

Fig.3

Camera motion controller

- It is a technology that enables precise motion control of camera for movie purposes.
- Widely used controllers are: Milo© , TECHNODOLLY© , Dykstarflex©
- TECHNODOLLY's features: automatically or manually controlled, shift of dolly proceed on the rail-way track or can be fixed, "teach-in", memory of movements, etc.

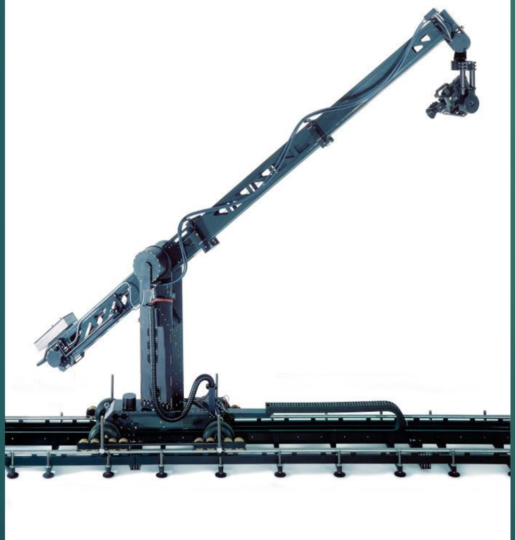


Fig.4

Fig.5

3D model

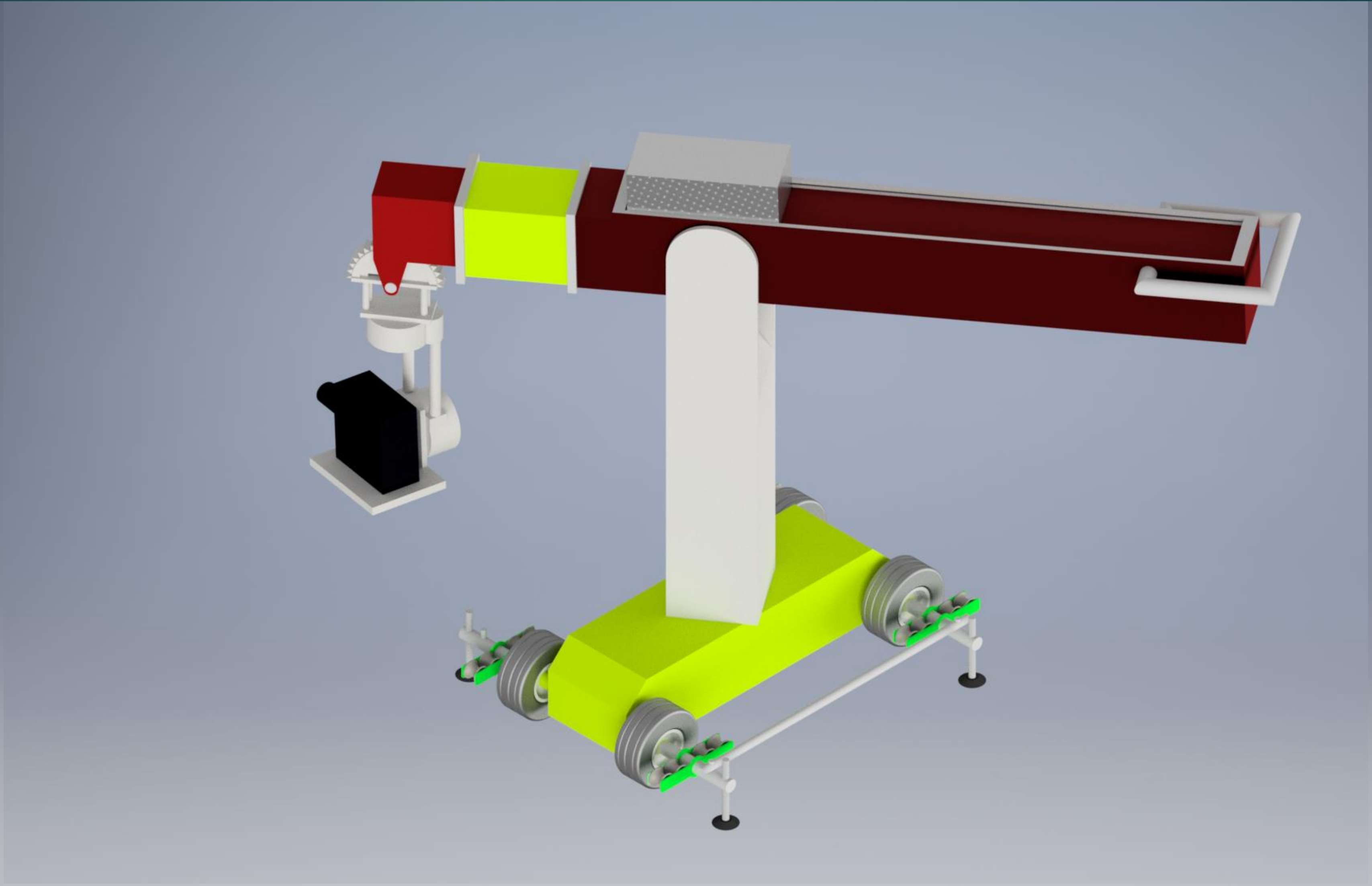


Fig.6

Kinematic analysis

- Closed-loop matrix method was chosen to provide a kinematic analysis.

$$\boldsymbol{T}_{12}\boldsymbol{T}_{23} \dots \boldsymbol{T}_{n-1,n}\boldsymbol{T}_{n1} = \boldsymbol{E}_4 \qquad (1)$$

Where: T_{ij} … homogeneous transformation matrices.

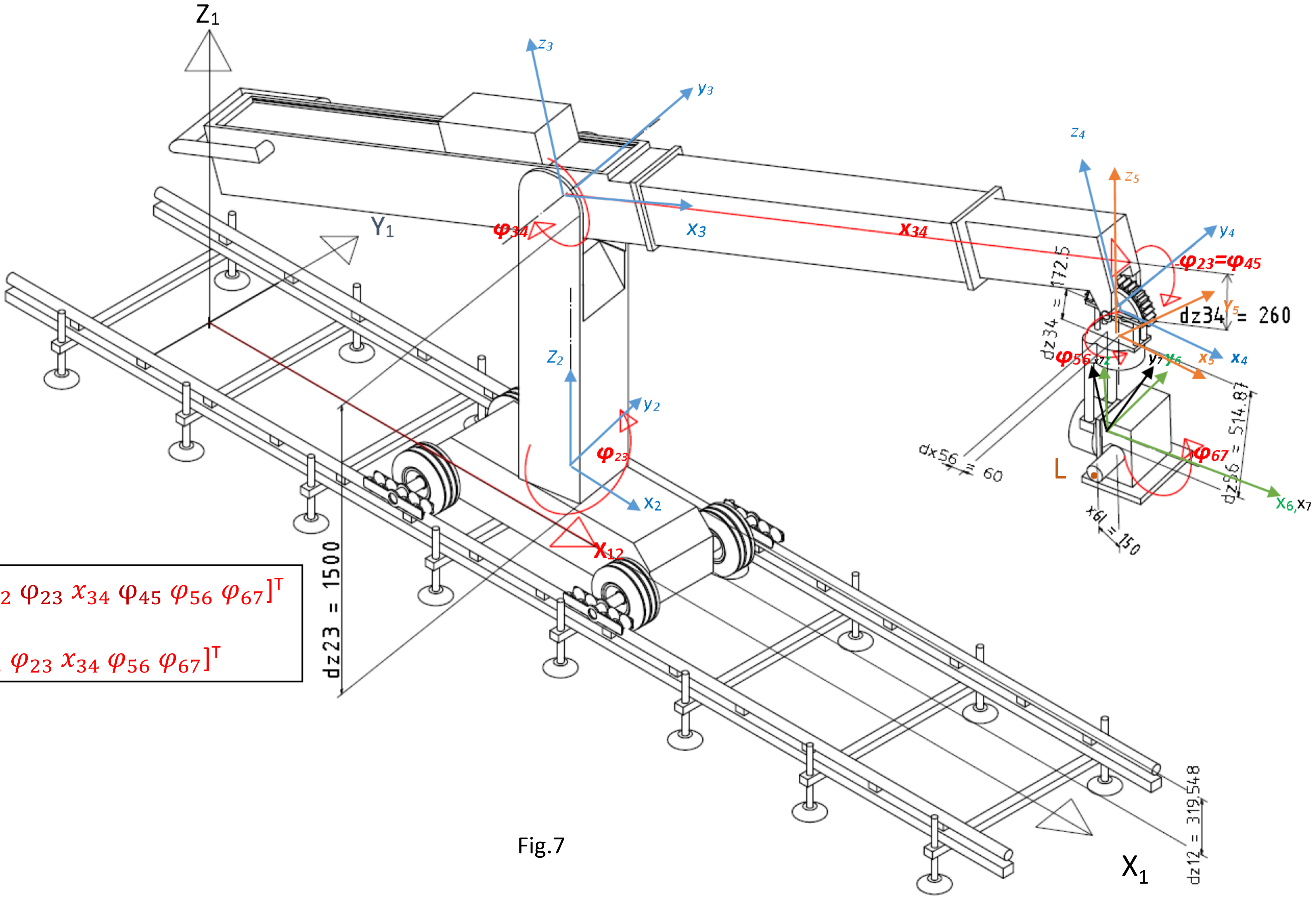
E_4 … 4x4 identity matrix.

- From this relation we can obtain 16 equations, out of which 4 are identities. Out of remaining 12 equations, only 6 are independent.

$$f_k(\boldsymbol{q}, \boldsymbol{z}) = \boldsymbol{0} \quad k = 1 \dots 6 \qquad (2)$$

Where: $\boldsymbol{q}_i$ i=1 up to 6 … independent coordinates (known parameters). Amount of **q** is the same as number of degree of freedom.

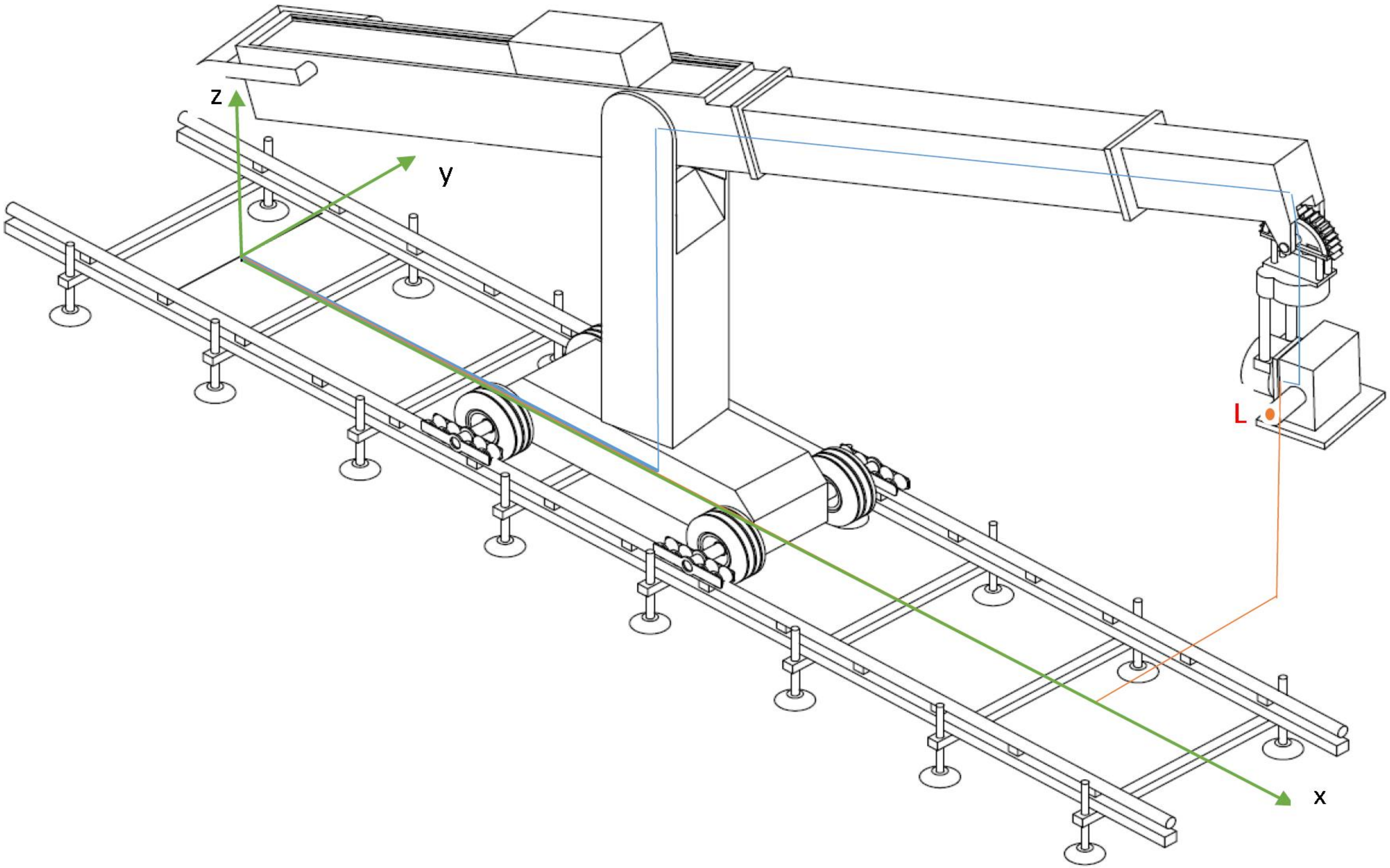
$\mathbf{z}_i$ i=1 up to m … dependent coordinates (unknown parameters). If number of **z** will exceed 6 coordinates, mechanism will have redundant constraints and problem will be statically indeterminate, i.e. amount of unknowns is more than number of independent equations.



$\mathbf{z}^* = [x_{12}\ \varphi_{12}\ \varphi_{23}\ x_{34}\ \varphi_{45}\ \varphi_{56}\ \varphi_{67}]^T$

$\mathbf{z} = [x_{12}\ \varphi_{12}\ \varphi_{23}\ x_{34}\ \varphi_{56}\ \varphi_{67}]^T$

Fig.7



Path to L point through all mechanism (**z**)

Path to L point immediately from base (**q**)

Kinematic analysis

Numerical solution

- After development set of equations (6), in order to find a set of dependent coordinates **z** for every change step of independent coordinates **q**, we are going to apply Newton-Raphson iteration method.
- For known initial values of coordinates **q** and **z**, denoted as $\mathbf{q}^{(0)}$ and $\mathbf{z}^{(0)}$, respectively, we can find next required parameters.

$$\boldsymbol{z}^{(k+1)} = \boldsymbol{z}^{(k)} + \lambda.\, \Delta\boldsymbol{z}^{(k)} \qquad (7)$$

Where: λ … scalar parameter. For every next iteration step it will decrease by 2. Beginning from λ_1, then $\lambda_2=\lambda_1/2$ etc.

$\Delta\boldsymbol{z}$ … vector, computed by Jacobi of function $f(\boldsymbol{q},\boldsymbol{z})$ with respect to $\mathbf{z}$ coordinates.

$$\Delta\boldsymbol{z} = -J_z^{-1} f(\boldsymbol{z}^{(k)}\boldsymbol{q}^{(k)}) \qquad (8)$$

Newton-Raphson iteration. Kinematic solver.

Block diagram for MATLAB®

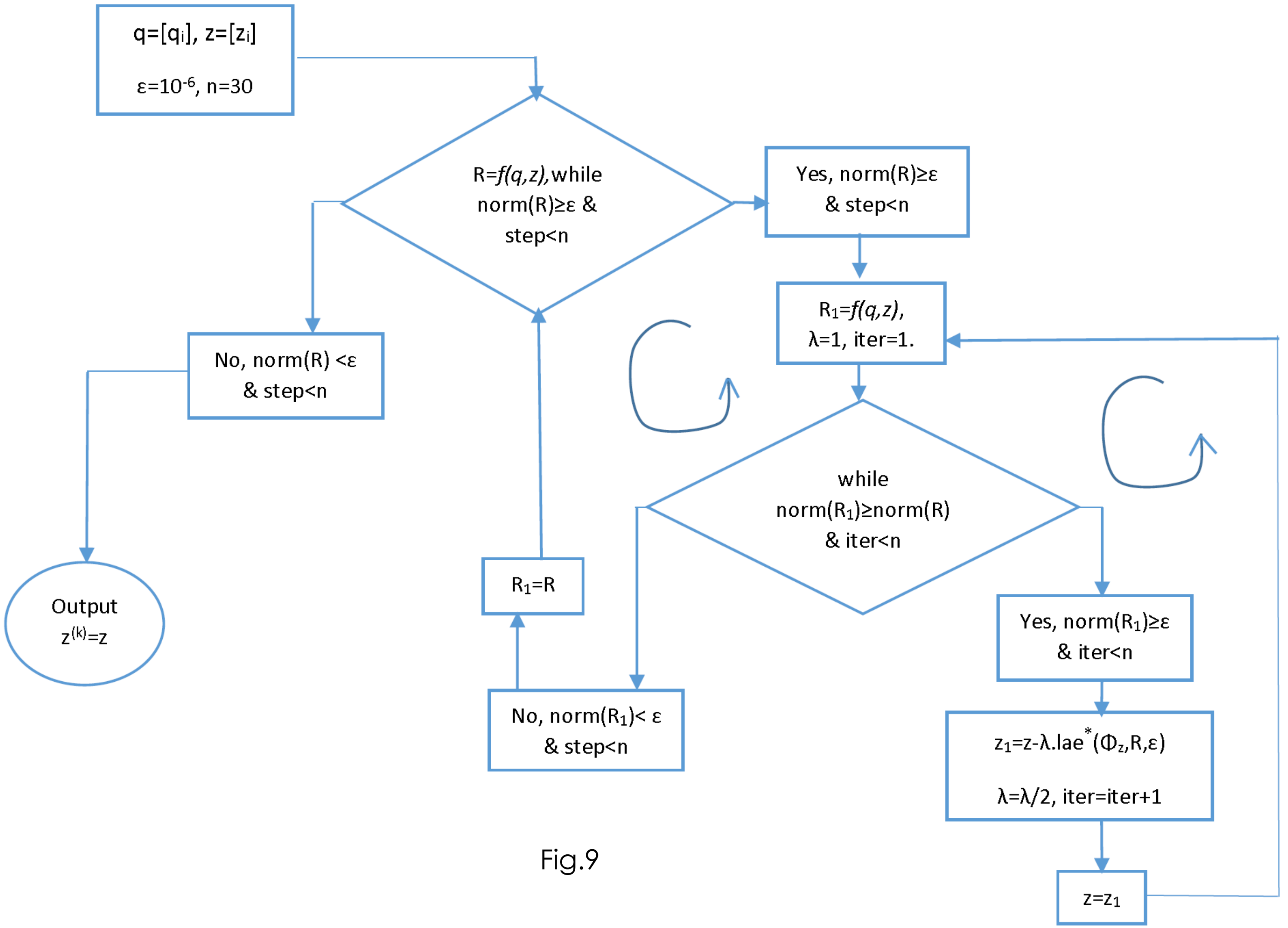
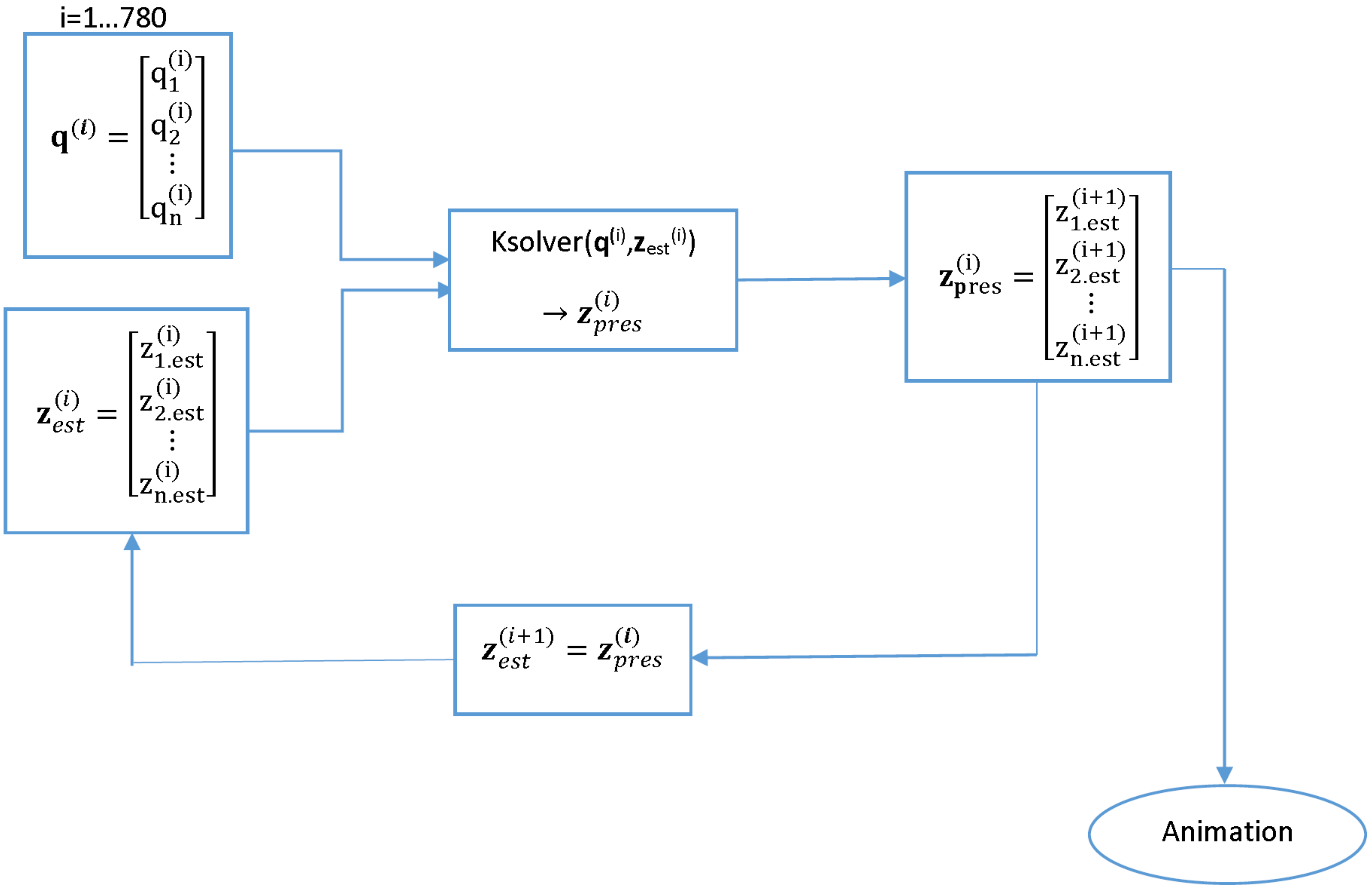


Fig.9



i=1...780
$\mathbf{q}^{(i)} = \begin{bmatrix} q_1^{(i)} \\ q_2^{(i)} \\ \vdots \\ q_n^{(i)} \end{bmatrix}$
$\mathbf{z}_{est}^{(i)} = \begin{bmatrix} z_{1.est}^{(i)} \\ z_{2.est}^{(i)} \\ \vdots \\ z_{n.est}^{(i)} \end{bmatrix}$
Ksolver($\mathbf{q}^{(i)}$,$\mathbf{z}_{est}^{(i)}$)
$\rightarrow \mathbf{z}_{pres}^{(i)}$
$\mathbf{z}_{pres}^{(i)} = \begin{bmatrix} z_{1.est}^{(i+1)} \\ z_{2.est}^{(i+1)} \\ \vdots \\ z_{n.est}^{(i+1)} \end{bmatrix}$
$\mathbf{z}_{est}^{(i+1)} = \mathbf{z}_{pres}^{(i)}$
Animation

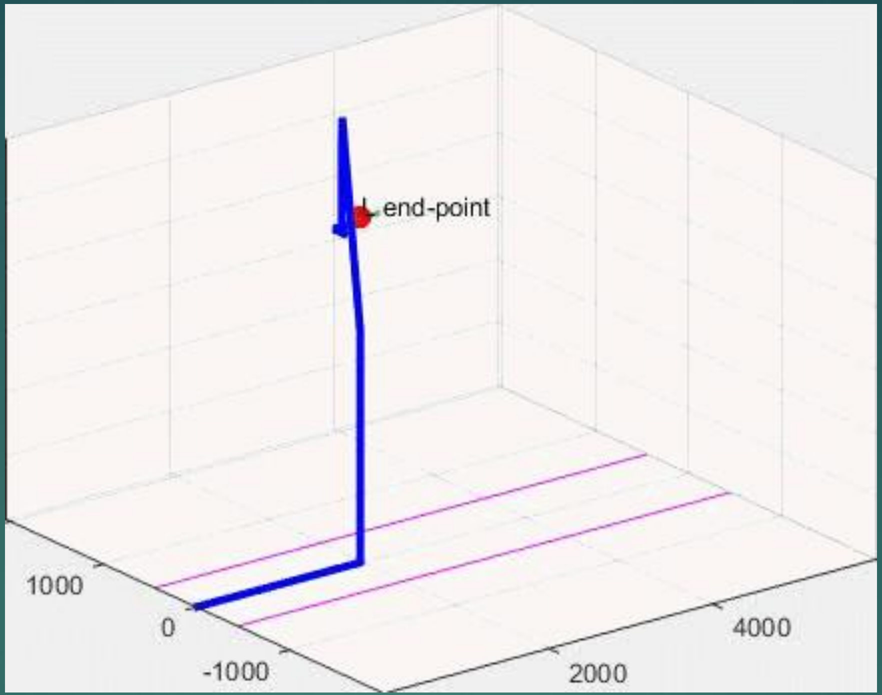


Fig.11

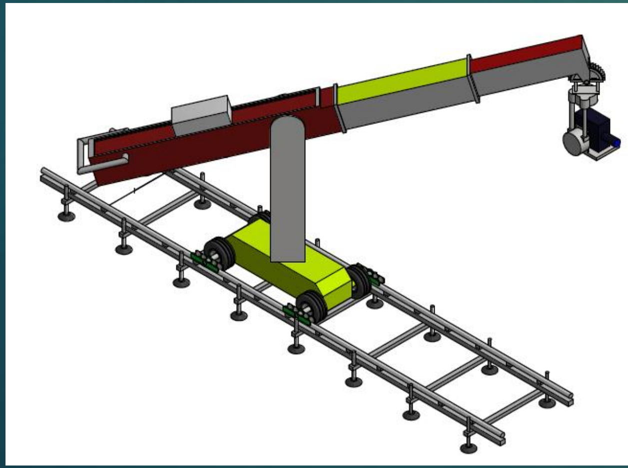


Fig.12

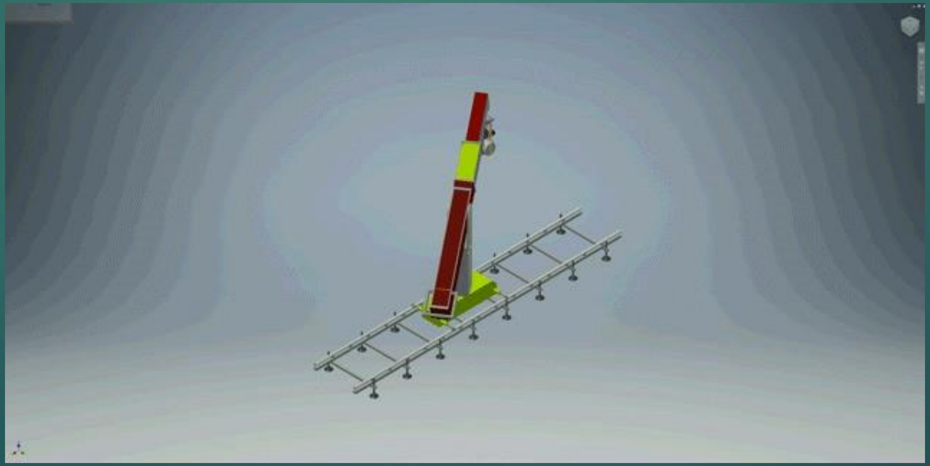


Fig.13

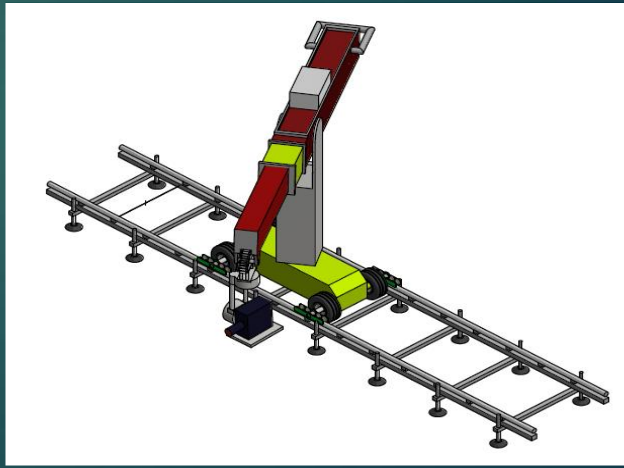


Fig.14

Conclusion

- In this work were introduced mechanisms that are widely used in movie industry. It clearly shows that this branch of art is in close relationship with mechanics.
- Next reached goal helped us to provide all needs to perform kinematic analysis and its mathematical simulation.
- Kinematic analysis was performed by usage of MATALB.
- Obtained results can be used for further development of analysis of this or similar kinds of mechanisms. For example analysis of mechanisms with redundant degrees of freedom or dynamic analysis.

Figures and their sources

- Fig.1 – intermittent mechanism: https://en.wikipedia.org/wiki/Intermittent_mechanism
- Fig.2 – Shark from movie "Jaws" 1975. http://filmmakeriq.com/lessons/film-screening-jaws/
- Fig.3 – Inception movie production. http://www.moviestillsdb.com/movies/inception-i1375666/f1ebd81f Copyright by Warner Bros.
- Fig.4 – Technodolly on track. https://picasaweb.google.com/103952987545626186879/TechnoDollyGalleryAtPicasa#5736078131926825810
- Fig.5 – Technodolly on fixed dolly. https://picasaweb.google.com/103952987545626186879/TechnoDollyGalleryAtPicasa#5736077933101901666
- Fig6. (a,b,c,d) – 3D model. Developed by author in Inventor 2016. a,b,c- model on railway track, d – on fixed leveling jacks.
- Fig.7 – Model for kinematic analysis showing changing coordinates and some model's dimensions. Developed in Inventor 2016
- Fig.8 – Loop figure of model. Developed in inventor 2016 by author
- Fig.9 – Block diagram of Newton-Raphson iteration method for kinematic solver. Author by MS Words 2013
- Fig.10 – Block diagram of Kinematic solution with usage of ksolver for MATLAB® approaches. MS words 2013. same
- Fig.11 – MATLAB® animation model
- Fig.12, Fig 14 – Initial position of dolly and final position of dolly respectively. Inventor 2016
- Fig.13 – Approximate 3D animated model of dolly, relatively corresponds to Fig.11, but not exact representation. Developed in Inventor 2016.