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NEW FINITE ELEMENT / MULTIBODY SYSTEM ALGORITHM FOR MODELING FLEXIBLE TRACKED VEHICLES

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- Challenges
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- Future Work

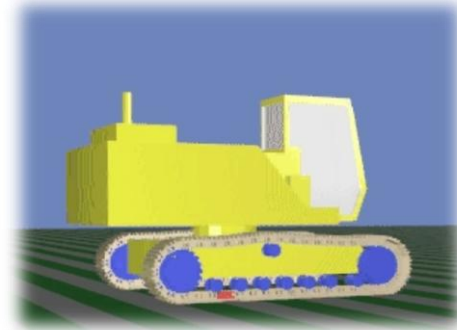


- Implementation of general MBS algorithms started in the mid seventies.
- First generation MBS codes were designed to solve systems that consist of rigid bodies only.
- Second generation MBS codes that allowed for modeling small deformation of flexible bodies with distributed inertia were introduced in the early eighties.
- Existing commercial MBS codes cannot systematically solve large deformation FE problems.
- The objective of this project is to address this important problem in order to develop a new generation of flexible MBS algorithms.
- These new algorithms can be effectively used to solve chain and tracked vehicle problems.

- TARDEC has a history of providing strong support for MBS research.
- This support led to the development of a new generation of MBS codes at the University of Iowa approximately 30 years ago.
- Successful integration of small deformation finite element (FE) and MBS algorithms was accomplished.
- This procedure has been implemented in most commercial MBS computer codes and is currently widely used in industry.
- TARDEC is currently working with the University of Illinois at Chicago on the development of a new generation of MBS codes based on the integration of computational geometry, large displacement FE, and MBS algorithms.



- Level of details included in tracked vehicle models depends on the available MBS simulation technology.
- First spatial MBS tracked vehicle model with rigid link chains was developed in the mid nineties.
- First MBS tracked vehicle model with rubber track (belt) was developed a few years ago.
- Development of flexible link chain models will require efficient integration of large displacement FE/MBS algorithms.
- This requires the use of new generation of MBS algorithms and computer programs .





- Chains have large number of joints and nonlinear inertia.
- Joints increase the number of nonlinear algebraic equations leading to a more complex algorithm.
- Development of accurate rigid link chains can be challenging.
- Efficient flexible link chain models cannot be developed using the floating frame of reference formulation implemented in most MBS codes.
- The use of new concepts and approaches is necessary.

$$\left. \begin{aligned} \mathbf{M}\ddot{\mathbf{q}} + \mathbf{C}_q^T \boldsymbol{\lambda} &= \mathbf{Q} \\ \mathbf{C}(\mathbf{q}, t) &= \mathbf{0} \end{aligned} \right\}$$



$$\begin{bmatrix} \mathbf{M} & \mathbf{C}_q^T \\ \mathbf{C}_q & \mathbf{0} \end{bmatrix} \begin{bmatrix} \ddot{\mathbf{q}} \\ \boldsymbol{\lambda} \end{bmatrix} = \begin{bmatrix} \mathbf{Q}_e + \mathbf{Q}_v \\ \mathbf{Q}_d \end{bmatrix}$$

PROJECT OBJECTIVES

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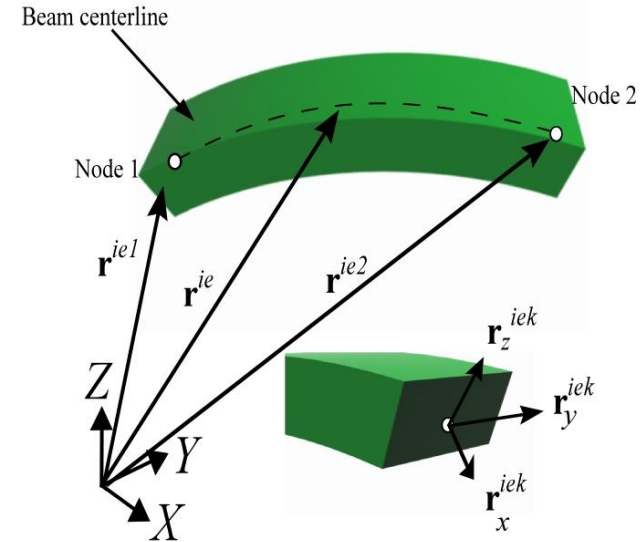


- Develop new generation of MBS tracked vehicle models with flexible link chains.
- In order to address the challenges in developing such models, the large displacement FE absolute nodal coordinate formulation (ANCF) is used.
- Use ANCF finite elements to obtain constant inertia leading to an optimum sparse matrix structure and zero Coriolis and centrifugal forces.
- Use ANCF finite elements to formulate chain linear connectivity conditions, leading to the elimination of dependent variables at a preprocessing stage (no chain joints in the MBS code).
- Demonstrate the new concepts and algorithms by implementing in a new tracked vehicle model.





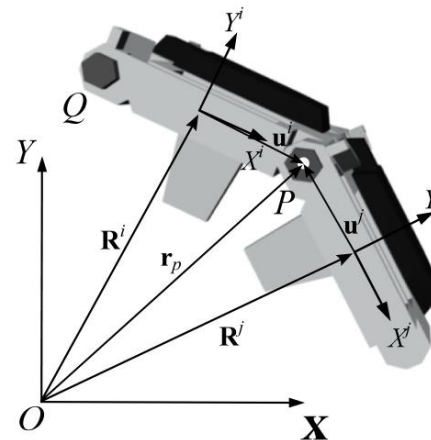
- ANCF finite elements correctly describe rigid body motion.
- The constant inertia matrix leads to optimum sparse matrix structure and zero Coriolis and centrifugal forces.
- General constitutive models can be used in the case of beams and plates.
- ANCF finite elements can be used to obtain linear chain connectivity conditions



$$\mathbf{r}^{ie} = \mathbf{S}^{ie} (x^{ie}, y^{ie}, z^{ie}) \mathbf{e}^{ie}$$

$$\mathbf{r}_p^i = \mathbf{r}_p^j$$

$$\left(\frac{\partial \mathbf{r}^i}{\partial \alpha} \right)_p = \left(\frac{\partial \mathbf{r}^j}{\partial \alpha} \right)_p$$



INTEGRATION OF FE/MBS ALGORITHMS

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- The new concepts and algorithms are implemented in the MBS code SAMS/2000.
- SAMS/2000 allows modeling systems that consist of rigid, flexible, and very flexible bodies.
- Rigid body formulation, floating frame of reference formulation, and ANCF are implemented.
- ANCF large displacement Cholesky coordinates can be used to obtain an optimum sparse matrix structure for articulated systems.
- Joint constraint equations are satisfied at the position, velocity, and acceleration levels.

$$\left. \begin{aligned} \mathbf{M}\ddot{\mathbf{q}} + \mathbf{C}_q^T \boldsymbol{\lambda} &= \mathbf{Q} \\ \mathbf{C}(\mathbf{q}, t) &= \mathbf{0} \end{aligned} \right\}$$



$$\begin{bmatrix} \mathbf{M}_{rr} & \mathbf{M}_{rf} & \mathbf{0} & \mathbf{0} & \mathbf{C}_{q_r}^T \\ \mathbf{M}_{fr} & \mathbf{M}_{ff} & \mathbf{0} & \mathbf{0} & \mathbf{C}_{q_f}^T \\ \mathbf{0} & \mathbf{0} & \mathbf{M}_{aa} & \mathbf{0} & \mathbf{C}_{q_a}^T \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{C}_s^T \\ \mathbf{C}_{q_r} & \mathbf{C}_{q_f} & \mathbf{C}_{q_a} & \mathbf{C}_s & \mathbf{0} \end{bmatrix} \begin{bmatrix} \ddot{\mathbf{q}}_r \\ \ddot{\mathbf{q}}_f \\ \ddot{\mathbf{q}}_a \\ \ddot{\mathbf{s}} \\ \boldsymbol{\lambda} \end{bmatrix} = \begin{bmatrix} \mathbf{Q}_r \\ \mathbf{Q}_f \\ \mathbf{Q}_a \\ \mathbf{0} \\ \mathbf{Q}_c \end{bmatrix}$$



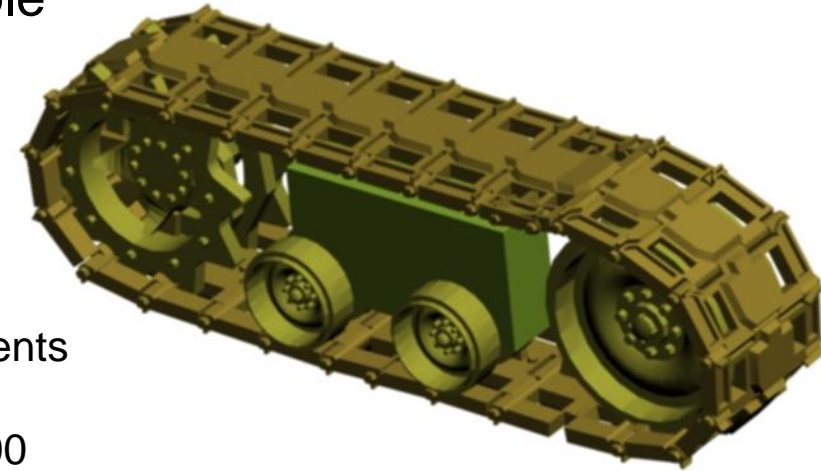
NUMERICAL EXAMPLE

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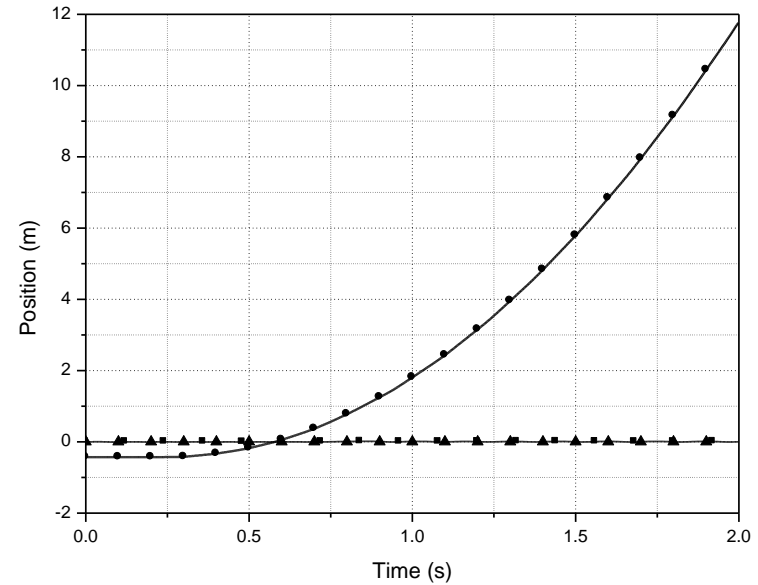
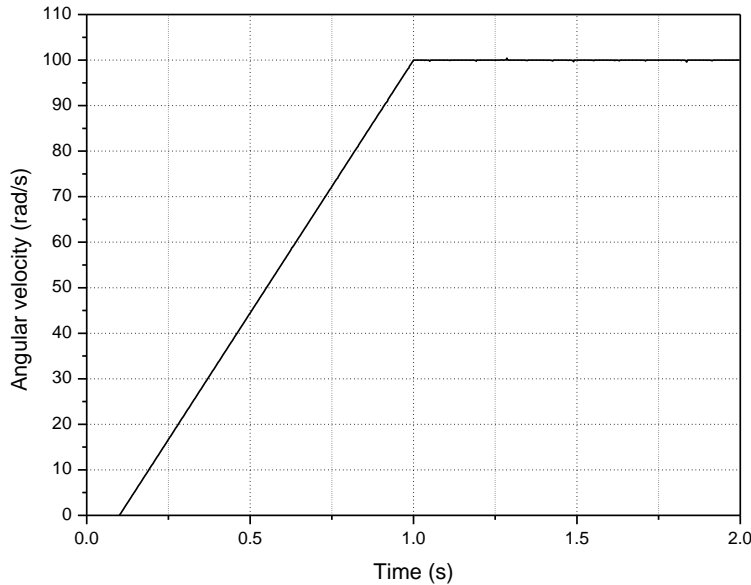
- A simple tracked vehicle model example may be used to illustrate the ideas presented.
- Model details:
 - The chain is modeled using 24 ANCF elements that have a rectangular cross section of dimensions $0.02\text{m} \times 0.4\text{m}$ and density of 2000 kg/m^3
 - The incompressible Neo-Hookean model and non-linear damping model are used to model the internal behavior of the rubber chain



RESULTS

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- Sprocket angular velocity

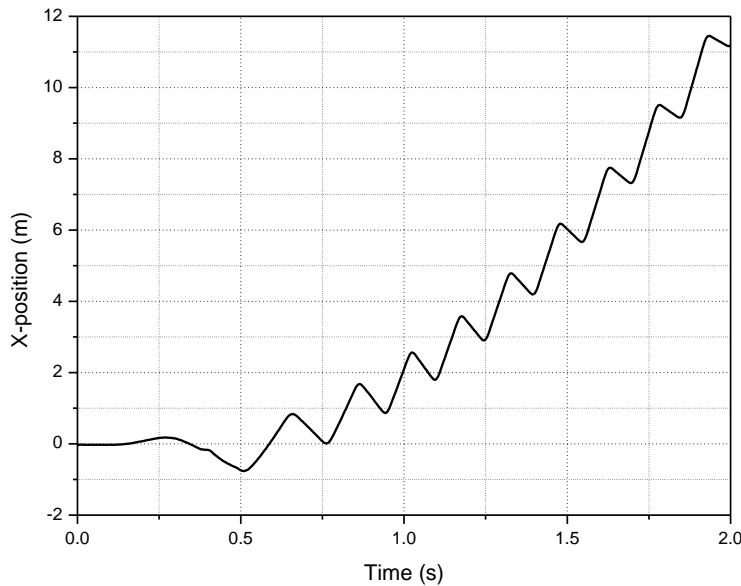
- Position of the center of mass of the chassis

- X coordinate
- ▲ Y coordinate
- Z coordinate

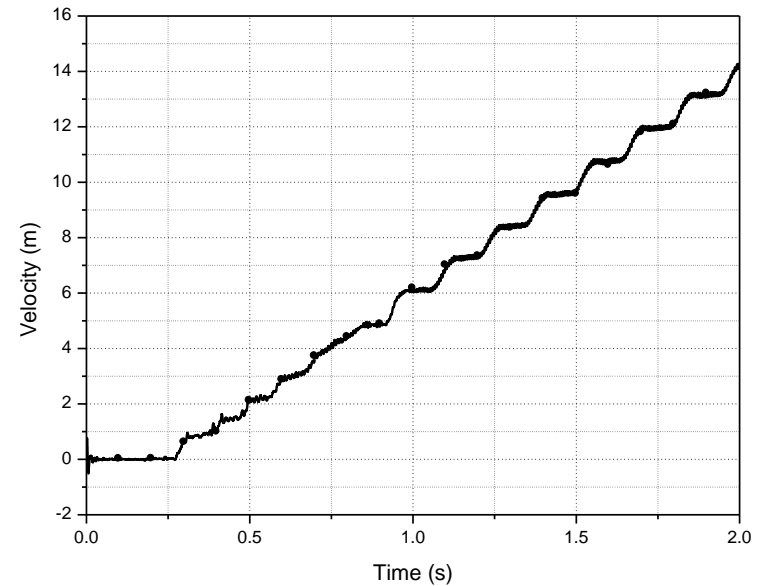
Results

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- X coordinate of the position vector of a point on the rubber chain

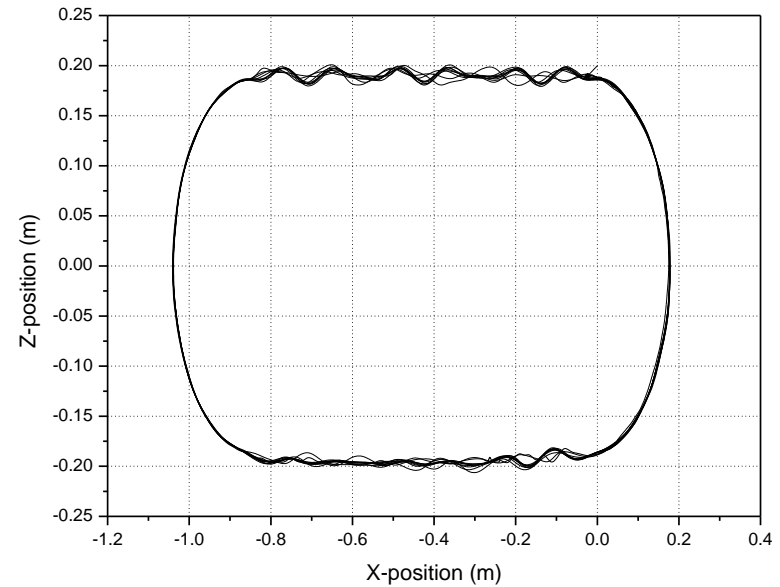
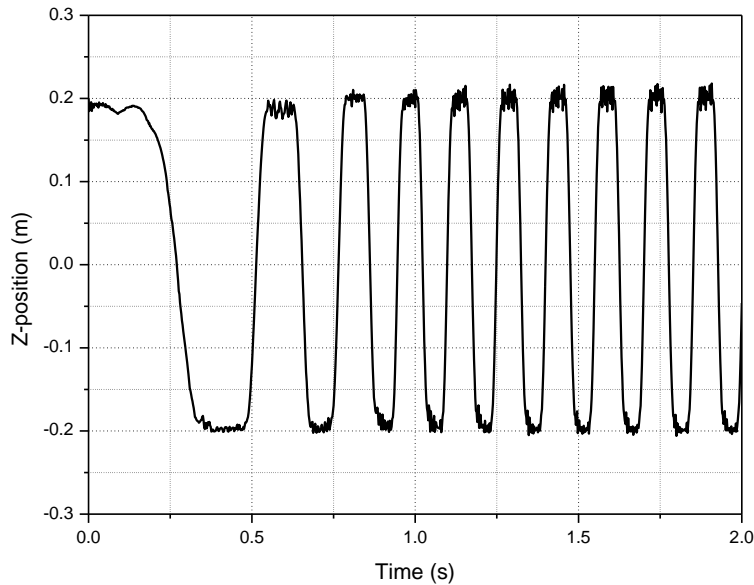


- X-velocity of the center of mass of the chassis

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- Trajectory of a point on the rubber chain

- Z coordinate of the position vector of a point on the rubber chain



- Integration of large displacement FE/MBS algorithms is necessary for the development of efficient and detailed tracked vehicle models.
- ANCF finite elements allow for the development of new FE meshes that have **linear connectivity** and **constant inertia**.
- Dependent variables can be systematically eliminated at a preprocessing stage (no need for joint formulation in the MBS code).
- The constant inertia allows for the development of an **optimum sparse matrix structure** of the equations of motion.
- The new concept was demonstrated using a chain example.



FUTURE WORK



- Develop a detailed tracked vehicle model with flexible link chains.
- The forces determined from the MBS simulation will be used to determine the link stresses.
- High deformation soil models may be included in the MBS environment.
- Comparisons between rigid and stiff track link tracked vehicles may be conducted in order to determine/outline the importance of deformation in tracked vehicle links (thermal stresses may be important).



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Questions?