DYNAMIC SYSTEM FOR TRACKED VARIABLE ELECTRONIC VEHICLE

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ABSTRACT
Tracked vehicles are widely popular in off-road mobile robot applications such as military and agricultural industries due to their mechanical configuration and traction. The controlling mechanisms of tracked vehicle are quite different than wheeled vehicles because of non-linear characteristics between the track and the ground. Mathematical analysis of observed vehicles is required in determining the vehicle state, heading of vehicle, compensation of sensor uncertainties for controlling of an autonomous off-road tracked vehicle. The suggested control method is based on estimating stiffness parameter of a physiotherapist's arm and producing impedance parameters of the robot to model the exercise motions. The effectiveness of proposed method is shown with simulation results. This research describes the tracked combine harvester dynamic model developed based on the sensor measurements for the controlling of tracked combine harvester and the application of automated navigation. Real time global positioning system and inertial measurement unit were developed on the observed multiple harvester for obtaining the position, direction of travel, angular rate etc.
Keywords: Impedance Control, Tracked combine harvester; RTK-GPS; IMU; Dynamic Model

1. Introduction

Soil parameter and track coefficients play an important role in determining the maximum track forces and moment of turning resistance developed by the tracked vehicles, which is a little bit difficult to measure in real time. A few researches have been done to estimate the soil parameter and track coefficients by using the theoretical and statistical methods. For instance, a method is described for estimating slip with a statistical method from the vehicle trajectory data, and sideslip angle for a tracked vehicle in real time [3, 4]. A methodology for calculating track coefficient is described for small to large scaled tracked vehicle for a terrain [2,5]. The estimation of track coefficient is also obtained with statistical method using the kinematic and dynamic model for a different terrain [6], and this result confirmed the dependence of track coefficient on vehicle turning radius and velocity [7]. In addition, the turning radius is a vital parameter for turning maneuverability that is estimated theoretically from the vehicle speed and angular rate based on kinematic model [1, 2]. But, these above parameters can be obtained in this research from the vehicle controlling parameters, position and inertial sensor measurements combined with the tracked kinematic and dynamic model.

In addition, transportation of patients to a hospital or calling a physiotherapist to a place where the patient is located consumes time and results in high costs. Considering such intricacies of a rehabilitation process, treatment becomes more complex due to economic and social constraints. Engineers working in the field of robotics focus on designing novel rehabilitation robots that can make a difference to deal with these difficulties. From the engineering point of view, applications of robotic technologies are suitable to solve these problems due to the following reasons [5]:

- ✓ Robots are excellent mechanisms that can achieve repetitive movements in pre-determined frequencies.

- ✓ Robotic mechanisms are easy to control under variable forces.
- ✓ Robots can produce required forces during the process of interaction between human and machine.

The working principle of this system was based on switching control structures corresponding to required training programme (isokinetic, steering, isometric, isotonic, physiokinetic, stretching, and assisted). Due to consider non-linear characteristics between the tracked combine harvester and terrain, and sensor measurement uncertainties, tracked combine harvester dynamic model is required for controlling precisely. For considering this matter, a tracked combine harvester dynamic model is developed based on Wong [2] with relevant sensor measurements in this research. Consequently, these tracked model equations are also used to determine the soil parameter and track coefficients of tracked combine harvester. In addition, the turning radius is obtained from the tracked combine harvester position by using the regression model, which is a good approach than theoretical turning radius. Therefore, the overall objectives concentrate in this research to develop a tracked dynamic model integrated with the positioning and inertial sensor measurements, which can be further used for the controlling of autonomous tracked combine harvester in non-linear condition, and also for the navigation application.

2. MODELLING MATERIALS

2.1. SYSTEM COMPONENTS

This research was conducted on a YANMAR AG1100 Tracked Combine Harvester which is equipped with an on- board computer to log sensor measurements from the RTK-GPS and IMU sensors by using serial ports as shown in Figure 1. The speed limit for the tracked combine harvester is maintained up to 2 m/s, and it is used for harvesting cereal crops such as paddy, wheat and even soybean. The RTK-GPS was used to measure position, direction of travel
and speed of the tracked combine harvester. 5-10 Hz update rate and 115200 Baud rate were used to fix for the RTK mode, where the maximum update and output rates of RTK-GPS is up to 20 Hz. The RTK correction signal was calculated from a Virtual Reference System (VRS) via an Internet connected to the on-board computer that logs the data from the GPS receiver through RS232C serial port.

Figure 1: Outlook of the tracked combine harvester equipped with RTK-GPS and IMU sensors.

2.2. TRACKED COMBINE HARVESTER DYNAMIC MODEL

Figure 2 shows the free body diagram of dynamic model for the tracked combine harvester which is moving on a general plane [1,2,4,6], turning to the left or counter clockwise, where its acceleration is in the positive x,y and φ directions. The external thrusts and resistive forces acting on the tracked combine harvester are FR, FL and RR, Rl, respectively. The value fy indicates the lateral friction force due to the effect of lateral soil shear. The Figure 2a is shown in the global reference frame XYZ; which indicates the tracked combine harvester turns around an instantaneous center of rotation (ICR). The angle β is called side slip angle, which is determined from the velocity Vc and the longitudinal axis x of the tracked combine harvester. It is assumed that the normal pressure distribution along the track is non-uniform, and the coefficient of lateral resistance μ is not constant. The instantaneous center of rotation must shift forwards of the tracked combine harvester centroid by the amount of D, as shown in Figure 2a, and this longitudinal shifting D depends on the tracked combine harvester lateral acceleration [2]. D is required to develop a net lateral force that accelerates the tracked combine harvester towards the instantaneous center of rotation, and also minimizes the resistive yawing moment [3]. For a tracked combine harvester of mass m and a moment of inertia about the center of mass I, the equations of dynamic motion can be written in the body reference frame by using eqns. (1-3), respectively.

$$m\ddot{x}_c = F_R + F_L - R_R - R_L - F_c \sin\beta \quad (1)$$

$$m\ddot{y}_c = F_c \cos\beta - \mu mg \quad (2)$$

$$I\ddot{\varphi} = \frac{\left[(F_R - R_R) - (F_L - R_L)\right]B}{2} - M_r \quad (3)$$

Where, the suffix c denotes coordinates fixed on the combine harvester. The centrifugal force F_C acting on the tracked combine harvester is shown in Figure 2b. The resultant F_C is given by $F_c = \frac{mV_c^2}{R}$; and the longitudinal and lateral centrifugal forces are given by eqns. (4) and (5), respectively.

$$F_{cx}\sin\beta = \frac{mV_c^2}{R}\sin\beta \quad (4)$$

$$F_{cy}\cos\beta = \frac{mV_c^2}{R}\cos\beta \quad (5)$$

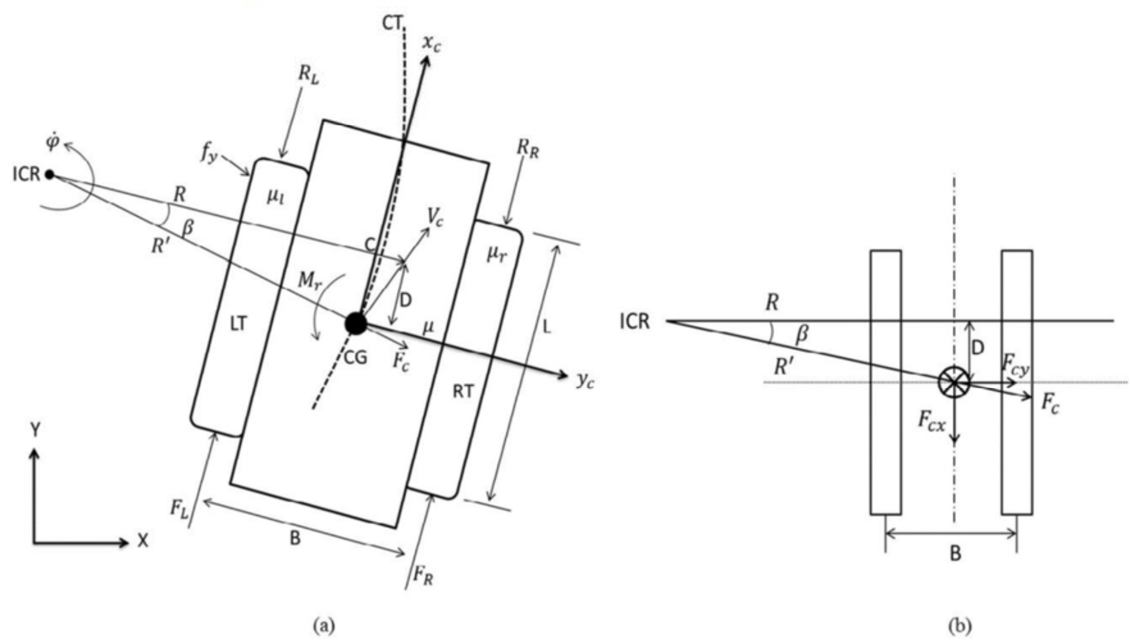

Figure 2: Free body diagram of the tracked combine harvester dynamic model (a. General forces acting on the harvester and b. Detail of centrifugal force, *Fc*).

3. METHODS

This dynamic system was verified by the field experiment in the Hokkaido University agricultural field. The tracked combine harvester with a proper configuration of RTK-GPS and IMU sensors were used during the experiment. In this case, the tracked combine harvester was moved on the concrete and soil ground. A set of input steering angles were fixed to run the tracked combine harvester at a circular and a sinusoidal trajectories. A constant 30 deg. of steering angle was chosen for circular trajectory; whereas ± 30 deg. steering command was for sinusoidal trajectory. Completely running at circular and sinusoidal trajectories, the position, direction and speed of the tracked combine harvester from RTK-GPS and angular rate from IMU were used to obtain the state of the harvester, track-soil interaction parameter, and track coefficients by using the tracked combine harvester motion model. The turning radius R was calculated based on the RTK-GPS positions by the eqn. (24) for tuning maneuverability. C/C++ programing language was used to describe the above parameters in this research.

4. RESULTS

Figure 3 shows the circular and sinusoidal trajectories of the tracked combine harvester on a concrete and soil ground in the agricultural field side of Hokkaido University, Japan, which was obtained from the measured and dynamic model. The measured trajectory is obtained from the fixed RTK-GPS on the tracked combine harvester with a set of input steering commands. Figure 5a and 5b indicates the circular trajectories on the concrete and soil ground while steering angle was 30°. The sinusoidal trajectories were obtained by a series of steering angle (± 30°) as shown in Figure 5c and 5d. The results showed that the dynamic model trajectories of tracked combine harvester matched with the measured trajectories fairly well. From the error analysis of circular trajectories, the RMS errors between the measured and dynamic model for the concrete and soil ground are 0.029 m and 0.012 m, respectively. The RMS error for concrete ground is higher than soil one because of sliding the tracked combine harvester on concrete ground. The RMS errors of sinusoidal trajectories are 0.034 m for concrete ground and 0.032 m for soil ground. This result indicates that the dynamic model trajectories for both grounds are consistent to the measured one. The measured and dynamic model yaw rate ϕ of the tracked combine harvester for the circular and sinusoidal trajectories. The measured yaw rate ϕ was obtained directly from the IMU sensor while the dynamic model yaw rate ϕ was calculated from the dynamic model equation. The dynamic model yaw rate ϕ can be influenced by the yaw moment of inertia I because it is a divisor factor. The yaw moment of inertia I is very important that reflects the tracked combine harvester's resistance to change its direction; which means a big yaw moment of inertia I makes the combine harvester slower to swerve or go into a tight curve, and it also makes it slower to turn straight again [10].

The RMS error of yaw rate ϕ obtained from the measured and dynamic model is 0.0004 rad/sec for both grounds of circular and sinusoidal trajectories. The RMS error indicates that the yaw rateϕ given by the dynamic model is closest to the measured yaw rateϕ. The lateral coefficient of friction μ was computed for the circular and sinusoidal trajectories. Figure shows the lateral coefficient of friction μ on concrete and soil ground for the tracked combine harvester over time. The lateral coefficient of friction μ may be varied with the high thrust and small turning radius as compared to large turning radius [12]. The results reveal that the estimated lateral coefficient of friction μ for both concrete and soil ground are same due to same turning radius R, but it may be higher for large steering command as compared to the small steering command. The longitudinal coefficient of friction μl and μr for the left and right tracks for circular and sinusoidal trajectories on concrete and soil grounds. Absolute value of $KO\ (t)$ is calculated, and impedance parameters $IR\ (t)$ and $BR\ (t)$ will be used to determine $\theta D(t)$ pattern to model physiotherapist's motion using (1), an example can be seen iN Fig.4 for parameters α = 0.1 and β = 3.

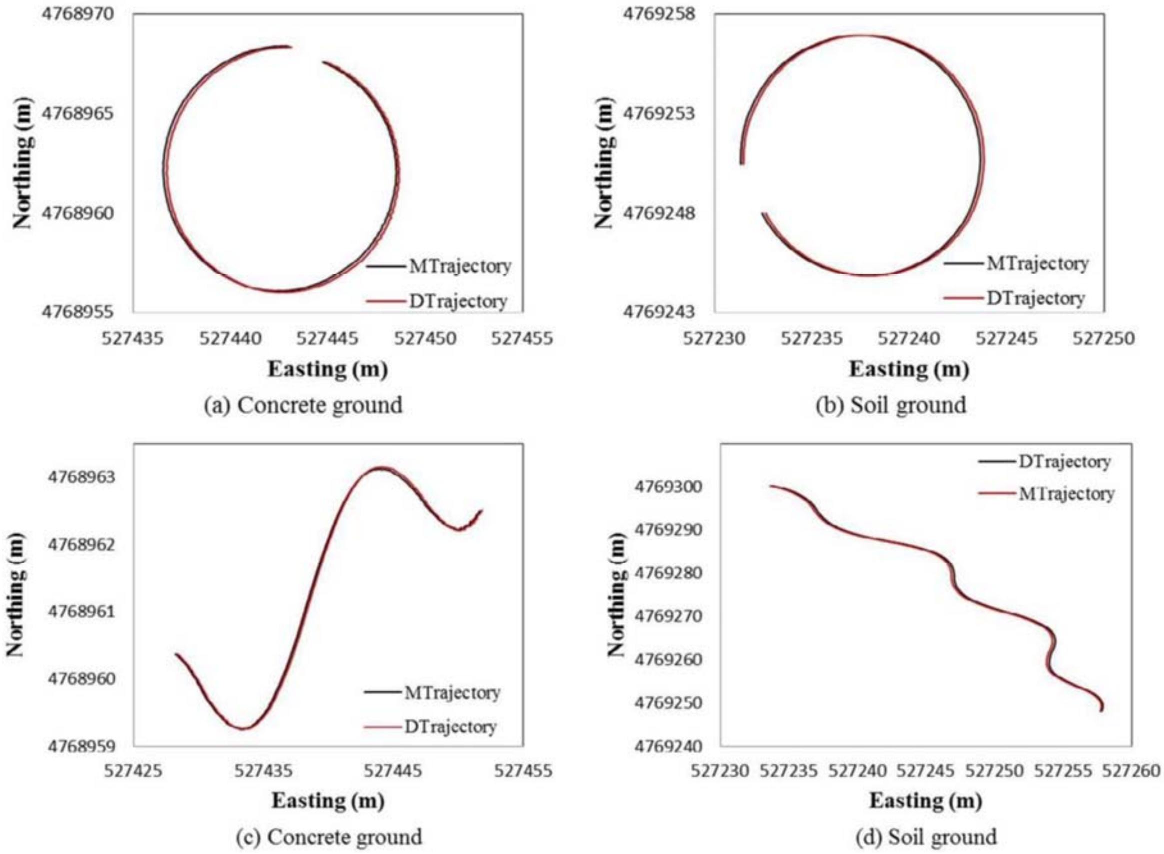

Figure 3: Measured Trajectory (MTrajectory) and Dynamic model trajectory (DTrajectory) of the tracked combine harvester which runs in a circular and sinusoidal way.

5. CONCLUSION

Simulation results show that adjusting impedance parameters that are in terms of estimated stiffness parameter of the physiotherapist's arm enables us to create a physiotherapist effect for passive lower limb flexion-extension exercises. This method gives us an error (max. 7° for parameters α=0.1,β=3) which is acceptable for passive flexion-extension movements for lower limb rehabilitation as can be seen in Fig.10, thus we can say that modeling physiotherapist's arm as a single spring is sufficient at least for passive flexion-extension exercises in lower limbs.

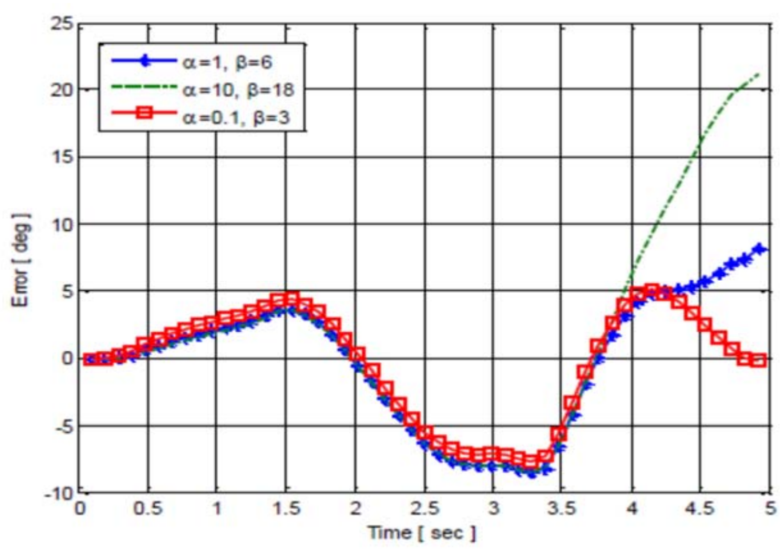

Fig4. Error between ΘD*(t)* and *ΘR(t)* parameters for α = 0.1 β = 3, α = 1 β = 6 and α = 10 β =18.

Future work includes experimental verification of the findings presented in this paper using Physiotherabot. A more sophisticated model for estimating α and β parameters can be based on Lyapunov approach and some identical parameters of patient, such as lower limb's mass and inertia can be used as a controller parameter in direct or indirect model reference adaptive control schemes. In addition to the single spring model, physiotherapist's arm can be modeled as a mass-damper-spring model to have more precise results. This paper describes the tracked combine harvester dynamic model integrated with the positioning and inertial sensor measurements to control the tracked combine harvester in non-linear characteristics. Based on the dynamic model and sensor measurements, the soil interaction parameter and track coefficients are obtained. The results of computed slip and track coefficients can be changed in terrain to terrain due to change of the tracked combine harvester steering and turning radius. The tracked combine harvester dynamic model is also verified by estimating the harvester state based on the sensor measurements. The turning radius from the RTK-GPS positions using regression model is better than theoretical turning radius. In addition, based on the computed track slip, sideslip angle, track coefficients and turning radius, the dynamic model can be used to control the autonomous tracked combine harvester precisely for non-linear condition in all terrain. In future research, the uncertainties of sensor measurements will be compensated by using this tracked combine harvester model specifically during turning maneuverability.

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