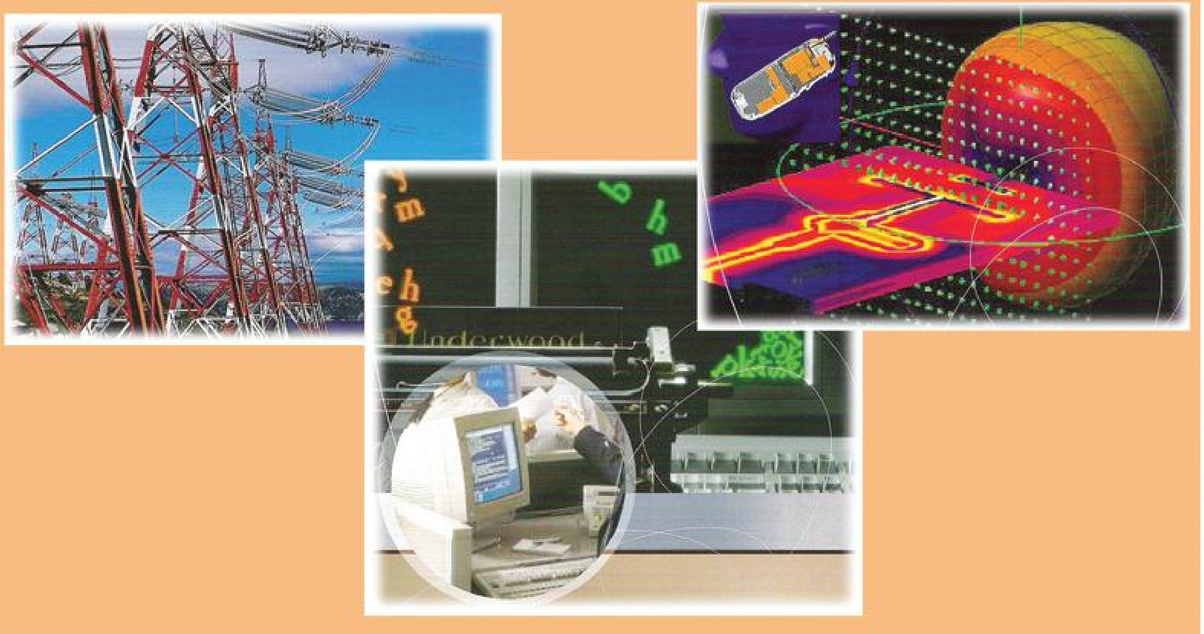

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Development of Low-cost Parachute Training Simulation System

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***Abstract*- This research was inspired by the problem in parachute training program in the Thai military training curriculum. The normal training routine consists of a physical training unit which suspends the body of the trainee while the trainer rotates the training set according to the given instruction routine. The current training system does not sufficiently provide the trainee the realistic perception of parachute flight operation. The parachute training simulation system is proposed to be the low-cost interactive training platform that enhances user's perception of motion and control of the parachute. The simulation system consists of the graphical user interface module that displays and updates the 3D scene according to the physical model of the parachute and the control of the steering line by the user. The parachute training simulation system is designed for parachute control practice for ground descending mission in windy situation.**

Keywords : Parachute Simulation , Parachute Training

I. INTRODUCTION

Currently, the parachute training curriculum for military training are classified into 4 steps.

Step 1: The theory of parachute control.

Step 2: Training and testing of trainee physical performance.

Step 3: Ground-based training of parachute control skill which includes.

3.1 Jumping from 34 feet tower.
3.2 Jumping 2 and 4 feet stage .
3.3 Ground-based parachute control skill training

Step 4: Air-based parachute training.

In the current training curriculum, the problem usually occurred on step 3.3 as shown in Fig. 1 ,when the trainee is unable to perceive the realistic motion of the parachute which is controlled by the trainer e.g. the trainee will control the direction of parachute by pulling the steering line and the trainer will rotate the training stage accordingly. The lack of realistic perception of motion and control in the existing training system caused the trainee to have insufficient experience in controlling the parachute and could lead to accident in the real air-based parachute training step.

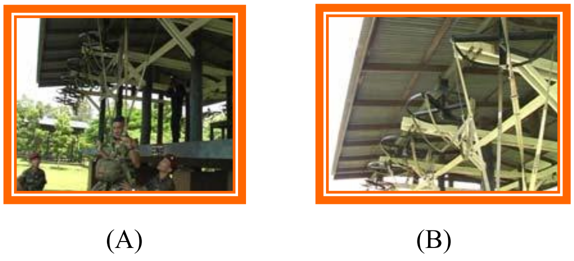

(A) (B)

Figure 1. (A) Training Style ,(B) Tools for Training

II. CONCEPTUAL FRAMEWORK

A. The interative parachute training simulation system

Parachute training system in virtual environment have been developed and improved over years for the use in military [1][2][3][6] and for sport and entertainment applications [4] [6]. Hi-speed computer, Hi-definition sensors and Head Mounted Display (HMD) have been used extensively in these research. These equipment usage results in the high cost of these existing simulation systems. The interactive parachute training simulation system consists of two majors elements: the graphical user-interface technology (software) and the steering input system (hardware). The 3D graphical scene is created by an environment simulation engine based on the real-time physical based simulation of the parachute motion in the air and the head motion of the user. The motion of the parachute is controlled by the user from the steering input system. Therefore, we propose the low-cost alternative of the parachute simulation system which is much cheaper and only required commodity equipment such as LCD projector as shown in Fig. 2. The graphical viewing system have the structure as shown Fig. 3.

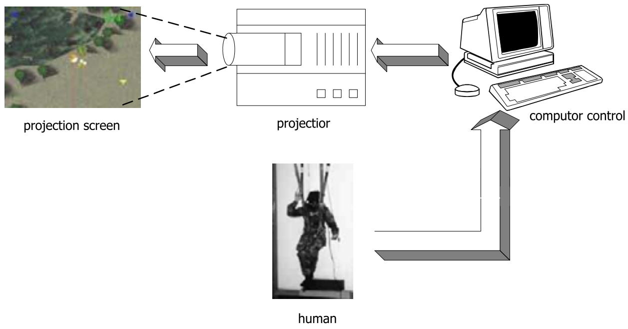


Figure 2. Design of Parachute Simulation System

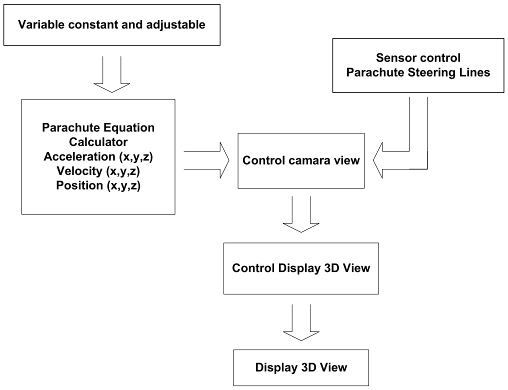


Figure 3. The design of a graphical viewing system

III. THEORY

A. Parachute physical based simulation

The motion of the parachute can be explained as 5 states as shown in Table 1 [8]. Parachute jump starts from the beginning of the jump until the point where the parachute is fully inflate and finally descend to the ground as shown Fig. 4 .

Table 1.
Function of Parachute Full Inflates [8]

	Time	Body	Status of Situation	Remark
1	$t \leq t_0$	Horizontal position	Freefall	
2	$t_0 < t \leq t_1$		Lines Extend	$t_1 - t_0 = 0.5$ sec
3	$t_1 < t \leq t_2$	Vertical position	Parachute Inflates	$t_2 - t_1 = 1.0$ sec
4	$t_2 < t \leq t_3$		Parachute Over Inflates	$t_3 - t_2 = 1.7$ sec
5	$t > t_3$		Final Descent	

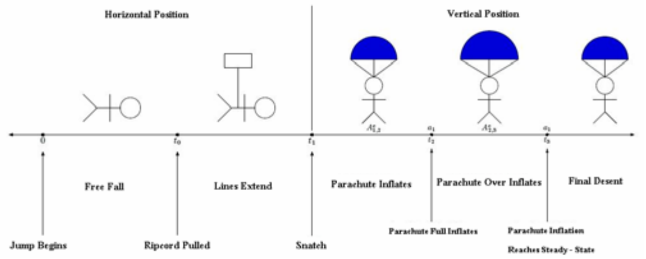


Figure 4. The 5 states of parachute jump cycle

Motion of parachute is affected by the gravity force: F_g. and the drag force: F_d. The sum of these forces are shown in (1).

$$\sum F = F_g + F_d \tag{1}$$

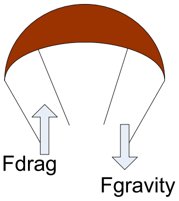


Figure 5. Forces affecting on the parachute

From these states of parachute jump cycle, the drag force is defined in (2). However, base on the condition of parachute jump, there are other factors that affects the forces acting to the body and the equipment which is given in (3).
F = total force, F_g = gravitational force, F_d = drag force, C_d = coefficient of drag, C_d^b = drag coefficient of skydiver body, C_d^e = drag coefficient of skydiver equipment, ρ = density of air flow, A^b = area of skydiver body, A^e = area of equipment ; $A_{1,2}^e$ on (t_1,t_2); $A_{2,3}^e$ on (t_2,t_3), h = height of jumper, H = height of jumping, a_1 = area of parachute, L = length of parachute lines, b_0 = area of body in horizontal position, b_1 = area of body in vertical position, m= weight of jumper include weight of parachute body, *v* and *a* are velocity and acceleration of the body.

$$F_d = \frac{1}{2}\left[C_d A \rho v^2\right] \tag{2}$$

Acceleration is given by the equation derived from sum of the force on the parachute body as in (4). Value of k in (4) derived from value of resistant force occurred from parachute body in (5).

$$F_d = F_d^b + F_d^e = \frac{1}{2}\rho\left[C_d^b A^b + C_d^e A^e\right]v^2 \tag{3}$$

$$a = \left[-g + \frac{kv^2}{m}\right] \tag{4}$$

$$\mathrm{k} = \frac{1}{2}\rho\left[\mathrm{C}_d^b \mathrm{A}^b + \mathrm{C}_d^e \mathrm{A}^e\right] \tag{5}$$

The value of k is different at each state of the process of each as shown in (6). The velocity of the parachute in (4) can be calculated by (7).

$$\mathrm{k} = \frac{1}{2}\rho\begin{cases} 1.95\mathrm{b}_0 & ,\mathrm{t} \leq \mathrm{t}_0 \\ 1.95\mathrm{b}_0 + 0.35\mathrm{b}_1 1\dfrac{\mathrm{t}-\mathrm{t}_0}{\mathrm{t}_1-\mathrm{t}_0} & ,\mathrm{t}_0 < \mathrm{t} \leq \mathrm{t}_1 \\ 0.35\mathrm{b}_1\mathrm{h} + 1.33\mathrm{A}_{1,2}^e(\mathrm{t}) & ,\mathrm{t}_1 < \mathrm{t} \leq \mathrm{t}_2 \\ 0.35\mathrm{b}_1\mathrm{h} + 1.33\mathrm{A}_{2,3}^e(\mathrm{t}) & ,\mathrm{t}_2 < \mathrm{t} \leq \mathrm{t}_3 \\ 0.35\mathrm{b}_1\mathrm{h} + 1.33\mathrm{a}_1 & ,\mathrm{t} > \mathrm{t}_3 \end{cases} \tag{6}$$

$$v(t)=\eta\left[\frac{1-e^{-\sigma t}}{1+e^{-\sigma t}}\right] \qquad ,v(0)=0 \tag{7}$$

when, $$\eta=\sqrt{\frac{gm}{k}} \qquad ;\sigma=\frac{2\eta k}{m}$$

B. 3D graphical viewing system & steering and head motion input system

3D graphical view rendering system is developed in C language using OpenGL library. The scene is updated from the viewpoint generated from the parachute equation of motion as shown in the previous section. The 3D graphical scene when the parachute descending is tested by rendering a 3D cone on the ground plane at various positions as shown Fig. 6. Steering and head motion input system is the electronic device that senses the motion of the steering line when the user pulls the steering line of the parachute in order to control the parachute and sense the head motion of the user . For the low-cost version of the parachute simulation system, potentiometers are mounted at the pulleys connected to the steering lines and the body-head suspension support. The potentiometer senses the motion of the left and right steering line then the data is used to update the physical based simulation of the parachute. The design of the low-cost parachute training simulation system is shown in Fig. 7.

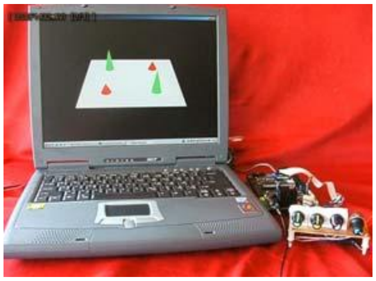


Figure 6. Test of the 3D viewing System together with the steering and head motion input systems

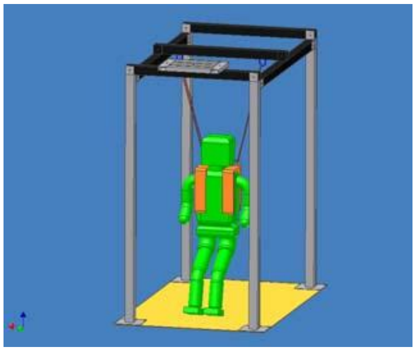


Figure 7. The model of low-cost parachute training simulation system

When the user pulls the steering line, it will cause the rotation motion of the parachute toward the pulling direction. The force equation of the parachute in (2) is modified by the angle of rotation caused by pulling the steering line(ϕ) and the turning radius (R) as described by (8) and (9) as show Fig.8 v and ω is the linear and rotational velocity of the parachute body.

$$\omega=\frac{g\times\tan\phi}{v} \tag{8}$$

$$R=\frac{v}{\omega} \tag{9}$$

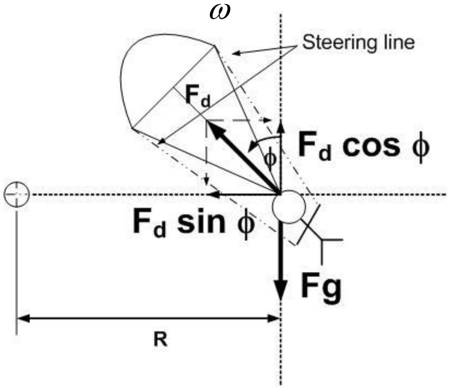
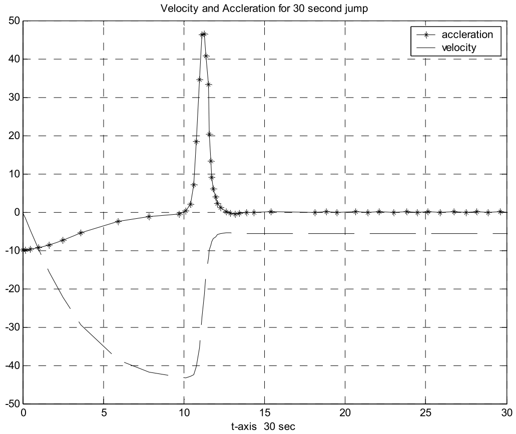


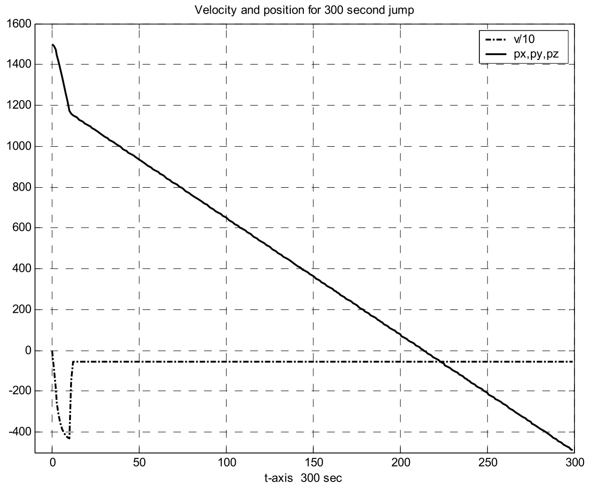
Figure 8. Parachute turning with the steering line control

IV. SIMULATION RESULT

The parachute model MC1-1C is used in this simulation. The MC1-1C model has the area of parachute (a_1) = 43.8 m^2 , length of parachute lines (L) = 8.96 m , area of body in horizontal position (b_0) = 0.5 m^2 , area of body in vertical position (b_1) = 0.1 m^2 , height of jumper (h) = 1.78 m , weight of jumper include weight of parachute body (m) = 97.2 kg , height of jumping (H) = 1,500 m (≈ 4922 ft). The simulated jump begins from time t_0 until the final decent at time t_3 as shown in figure 3.2. Different states of jump is defined by time: t_0 to t_1 = 0.5 second (Lines Extend) , time: t_1 to t_2 = 1.05 second (Parachute Inflates) , time: t_2 to t_3 = 1.7 second (Parachute Over Inflates). Take these values into parachute equations (4), (7) which can find the answer by using mathematical analysis program (MATLAB) as below Fig. 9.



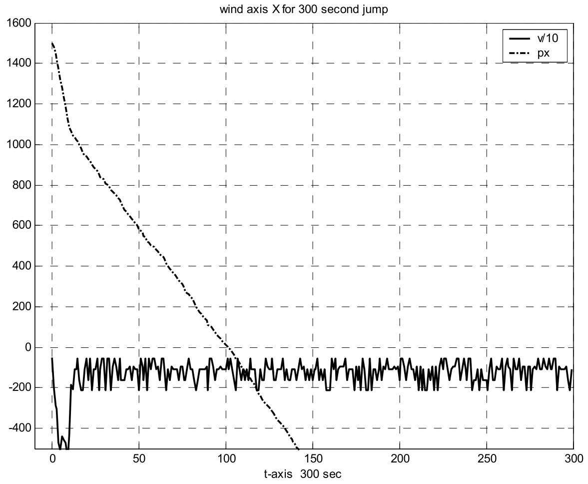
(a)



(b)

Figure 9. (a) Acceleration and velocity of parachute movement
(b) Position and velocity of parachute without external wind forces

In order to simulate windy situation necessary in parachute training exercise, the wind force is added into the parachute equation of motion. The wind force is added in axis X and Y. We can observe that when the wind force is added, the wind force directly affects the velocity and the position of parachute as shown in Fig. 10.



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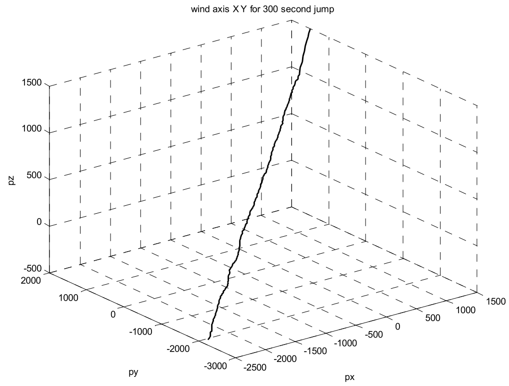

(b)

Figure 10. (a) Position and Velocity of parachute when the wind force is added in X axis (b) Position of parachute when the wind force is added in both X and Y axis

V. CONCLUSION

The low-cost parachute training simulation system consists of the physical based simulation of the parachute motion and the user interface subsystem including a 3D graphical viewing system and the steering & head motion input system. The physical based simulation of the parachute is tested with and without external wind force. The next step of this research is to test the overall performance of the low-cost parachute training system whether it can improve the skill of the trainee for ground descending mission in windy situation.

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