A Simulation of 3-D Navigation System of the Helicopter based on TRN Using Matlab

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ABSTRACT

This study has been carried for the development of the basic algorithm of helicopter navigation system based on TRN (Terrain Referenced Navigation) with information input from the GPS. The helicopter determines flight path due to Origination-Destination analysis on the Cartesian coordinate system of 3-D DTM. This system shows 3-D mesh map and the O-D flight path profile for the pilot's acknowledgement of the terrain, at first. The system builds TCF (terrain clearance floor) for the buffer zone upon the surface of ground relief to avid the ground collision. If the helicopter enters to the buffer zone during navigation, the real-time warning message which commands to raise the body pops up using Matlab menu. While departing or landing, control of the height of the body is possible. At present, the information (x, y, z coordinates) from the GPS is assumed to be input into the system every 92.8 m of horizontal distance while navigating along flight path. DTM of 3" interval has been adopted from that which was provided by ChumSungDae Co., Ltd..

Keywords : 3-D Navigation, TRN (Terrain Referenced Navigation), GCAS (Ground Collision Avoidance System), TCF (Terrain Clearance Floor)

요 약

본 연구는 지형참조항법(TRN; Terrain Referenced Navigation)에 근거하는 헬리콥터 항법 시스템을 위한 기본 알고리즘을 개발하기 위해 수행되었다. 현재 본 연구에 위성항법장치(GPS; Global Positioning System)로부터의 정보(X, Y, Z 좌표)는 비행체가 항로를 비행하는 중 매 92.8m의 수평거리로 환산하여 수신되는 것으로 가정하였다. 비행체는 3차원 직교 좌표 체계(Cartesian coordinate system)로 표현되는 수치지형모델(DTM;

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Digital Terrain Model)상에서 시점(Origination)-종점(Destination) 분석 기법에 의해 항로를 결정한다. 본 시스템은 우선 조종사에게 지형의 사전 인식을 위해 시점-종점 주변 3차원 지형도와 항로의 종단면도를 보여준다. 본 시스템은 직접적인 지상 충돌을 피하기 위해 지형 여유 층면(terrain clearance floor)의 개념을 도입, 기복 지형 표면에 일정 높이의 완충 공간을 설정한다. 만약 비행체가 항행 중 완충 공간에 접근하게 되면 본 시스템은 실시간으로 즉시 경고음과 메시지를 발한다(Matlab 메뉴를 사용하였음). 물론 헬리콥터의 이착륙 시에는 불필요한 경고를 발생시키지 않기 위해 완충 공간 조정은 가능하다. 수치지형모델은 (주)첨성대가 확보하고 있는 3초 간격의 DTM을 채택, 작성하였다.

주요어 : 3차원 항행, 지형참조항법, 지상충돌회피기법, 지형 여유 층면

1. Introduction

In general, the mission computer in the aircraft has 3 functions complementing each other. The first is INS (Inertial Navigation System), the second is GPS (Global Positioning System), the last is RadAlt (Radar Altimeter).

INS is the basic function which can predict the flight-path without any complementary GPS or RadAlt for further navigation at most 20 minutes.

Although the helicopter can be included in general aircraft, due to it's characteristics which flies at low altitude, the collision to ground/ground facilities is the most serious problem during navigation, specially while coming across bad weather.

Several GCAS (Ground Collision Avoidance System) including PGCAS (Predictive GCAS) by the BAE System Inc. [5] are being operated in the world wide nowadays.

In PGCAS, the flying aircraft scans forward air route with several distance intervals and makes worst ground surface profile, collecting the highest elevation from each circular arcs scanned. The more the scanned arcs, the more lagged the processed results.

Most of GCAS adopts the concept of TCF (Terrain Clearance Floor) which means the surplus height added to that of ground relief surface.

The space between TCF and ground surface is a kind of buffer zone for the aircraft to avoid the close encountering the ground surface during navigation.

At present Korean Air Force is considering a GCAS on KHP (Korean Helicopter Project), too.

The system in this simulation produced TCF 50 m above the elevation of DTM, the adding value of which was determined for experimental purposes.

The system also generates the visual-auditory warnings promptly when the aircraft approaches TCF, which would be decided with the aid of GPS position during navigation.

The configuration of simulating helicopter navigation upon the ground relief is as the Figure 1.

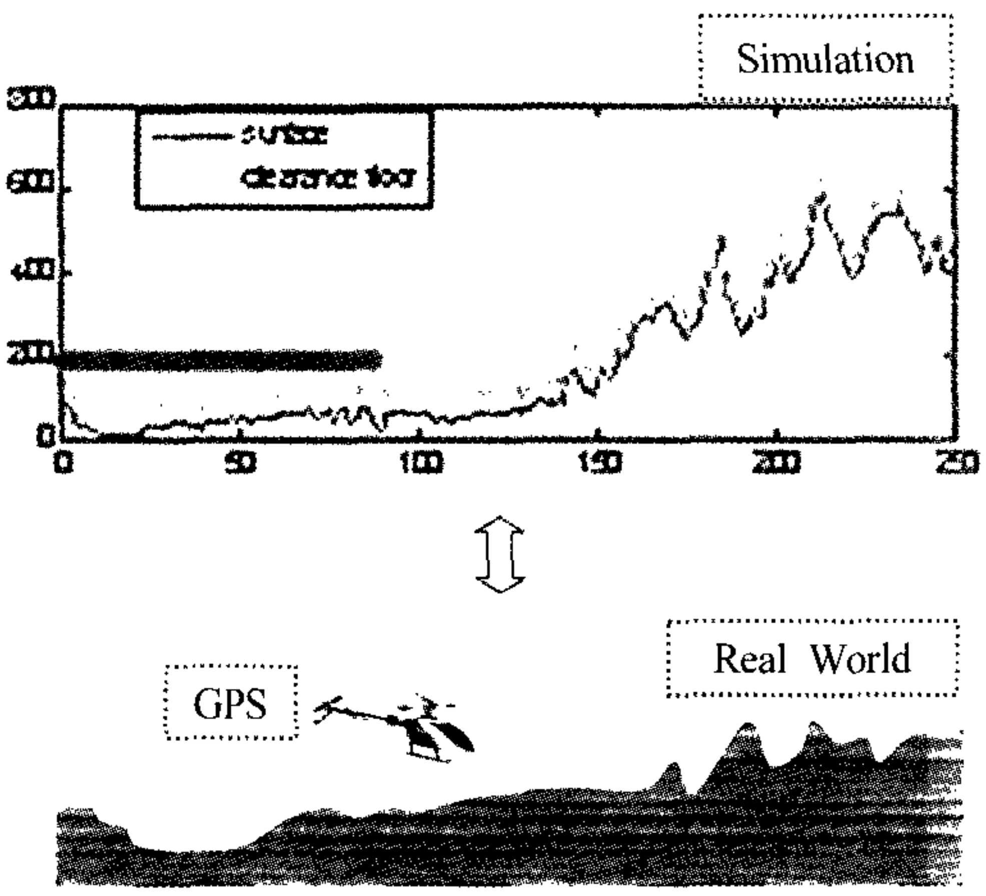

Figure 1. Configuration of the system

2. Helicopter navigation system

This study has been carried on for the development of the basic algorithm of helicopter navigation system based on TRN with information input from GPS.

This system determines flight path due to Origination-Destination analysis on 3-D DTM.

This system shows 3-D mesh map and the O-D path profile for the pilot's acknowledgement of the terrain ahead of the navigation.

The system builds TCF for the buffer zone upon the surface of ground relief. Whenever the helicopter enters to the buffer zone during navigation, the warning message which commands to raise the body pops up using Matlab menu. The helicopter is assumed to achieve necessary vertical ascending and descending while navigating. While departing or landing, control of the height of the body as well as TCF is possible.

In the study, 3-D coordinates (x, y, z) frame adopted Cartesian system and follows ordered n-tuples method [3].

At present, the information (x, y, z) from the GPS is assumed to be input into the system every 92.8 m of horizontal distance while navigating along the flight path.

2.1 DTM and 3-D representation

KHP is expected to consider DTM of 30 m interval by SPOT/SRTM, nevertheless this study has adopted that of 3" interval which was provided by ChumSungDae Co., Ltd, for experimental purposes.

The quadrangle area between East 127-128° and North 37-38° in the demilitarized zone in Korean peninsula was sampled into 1201 points × 1201 points with 3" interval which means about 92.8 m as the Figure 2.

Being assumed earth's radius 6378 km, the distance between neighboring points is $2\pi \times 6378\ \text{km} / (360° \times 60' \times 60'') \times 3 = 92.8$ m upon the circumference of the earth's great circle.

The quadrangle section of 200 points (W-E, X direction) and 150 points (N-S, Y direction) were extracted as the pilot area to represent 3-D topography as the Figure 3. Obser-

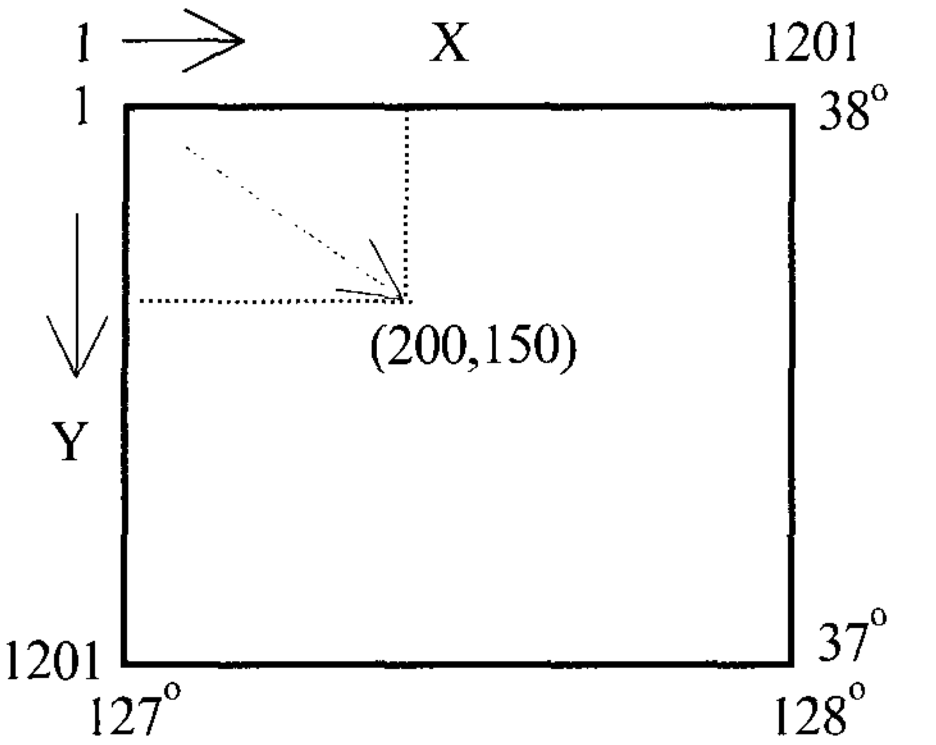

Figure 2. Pilot area

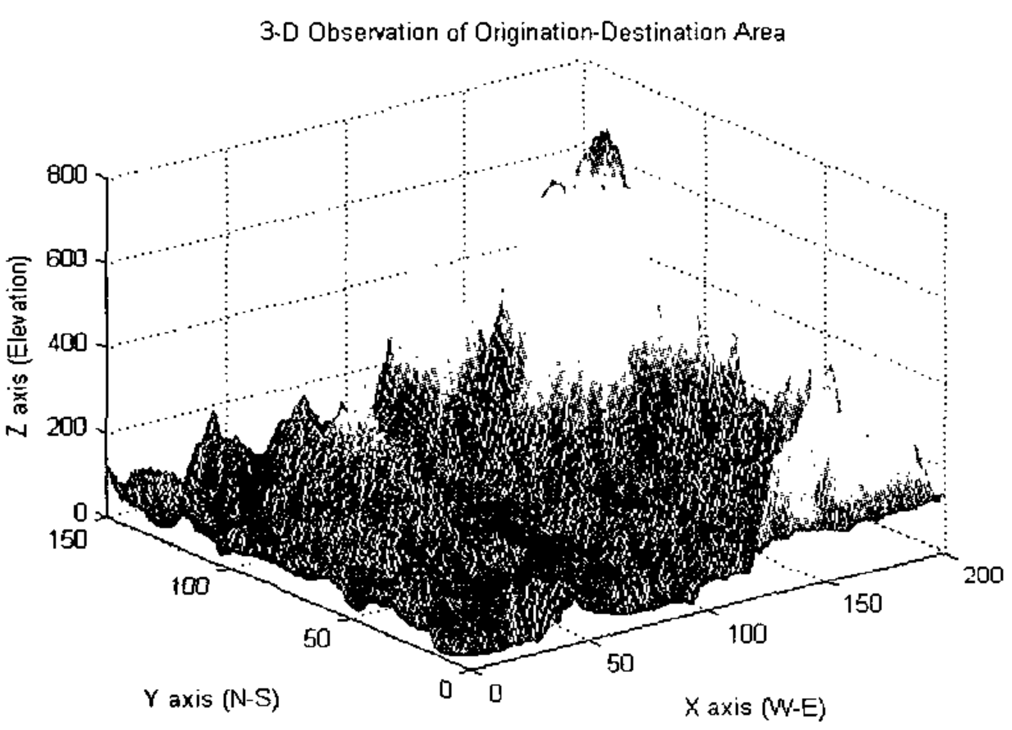

Figure 3. Representation of 3-D Digital Terrain Model

vation point is on -37.5° of azimuth and 30° of elevation angle according to Matlab's default [1].

The system also shows contour map with Origination-Destination direction as the Figure 4.

Azimuth 36.87° is sustained during helicopter navigation due to ArcTan (150/200) without any deviating from the flight path upon X-Y plane.

2.2 Origination - Destination Profile

The helicopter originates from (0,0,85) coor-

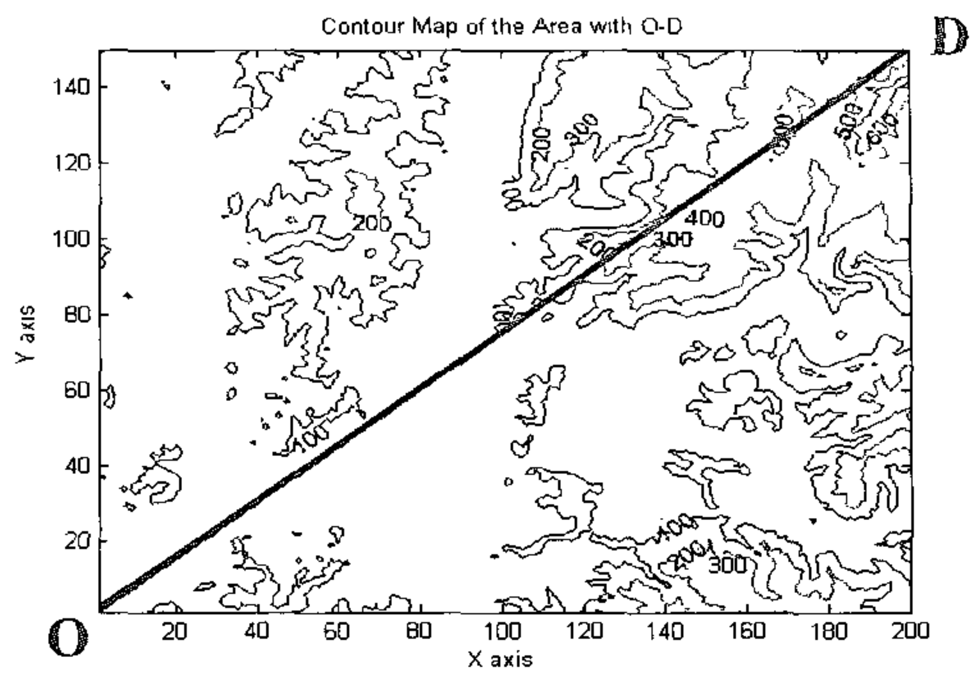

Figure 4. Contour Map and Air Route O-D

dinates and destines to (200,150,457) coordinates. The Origination-Destination profile is shown along the O-D axis with the distance, root square of $(x^2 + y^2)$ to pilot as the Figure 5. Height of 50 m was added to that of the ground surface as the terrain clearance floor to avoid direct collision during later navigation.

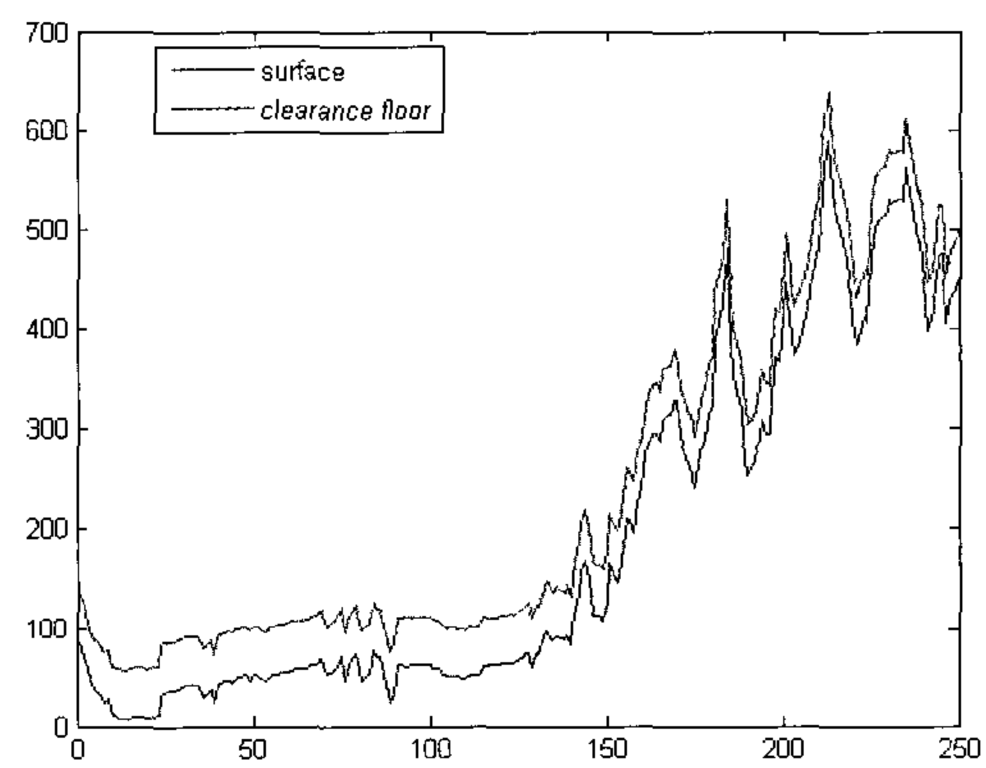

Figure 5. O-D Profile along Air Route

2.3 Real time monitoring the helicopter position

The flying velocity is the vector function of the present position/time as the follows.

$V(p) = [v_x(p),\ v_y(p),\ v_z(p)]$,

Suppose that a Cartesian coordinate system has been introduced, then the necessary and sufficient condition for V(p) that it could be differentiable at position p is equivalent to that its three components of V(p) is differentiable at position p. That is, if

$v_m'(p) = \lim_{\triangle t \to 0} \{v_m(v + \triangle t) - v_m(t)\} / \triangle t$

where (m = x, y, z) is true.

then $V'(p)=[v_x'(p),\ v_y'(p),\ v'_z(p)]$ [2].

Therefore, comparing the position (x, y, z) at present to that at previous input data which is informed regularly from GPS, the velocity and direction can be calculated as follows.

Distance between regular time interval = $\mathrm{Root}[(x-x_p)^2 + (y-y_p)^2 + (z - z_p)^2]$

Instant Velocity = Distance / Time interval of GPS.

Instant Direction = $(x-x_p)i + (y-y_p)j + (z-z_p)k$

In the system the helicopter assumed the vertical raise and fall during navigation, nevertheless general flying vehicle could not disregard the inertia.

1) When preparing the takeoff on the ground at origination

The helicopter stands at the ground (0, 0, 85) in the airport .

The menu using m function of Matlab [4] which informs the present elevation and departing pops up by following algorithm embedded as M-file for instance.

```
% show departing menu
h_up=[100,150];beep;
k=menu(sprintf('이륙합니다. 현재
고도 [%d m] \n수직 상승!',h),
'+100','+150M');h=h+h_up(k);
for i=1:1:m
    j=i*(n/m); subplot(2,1,1);
    hold on plot(i,j,'ro');
    ij=round(sqrt(i^2+j^2));
    if z2(ij) > h
% popup menu needed
```

And monitoring display of present position (x, y, z) of the helicopter on the contour map as well as on the flight path profile is shown to the pilot as the Figure 6.

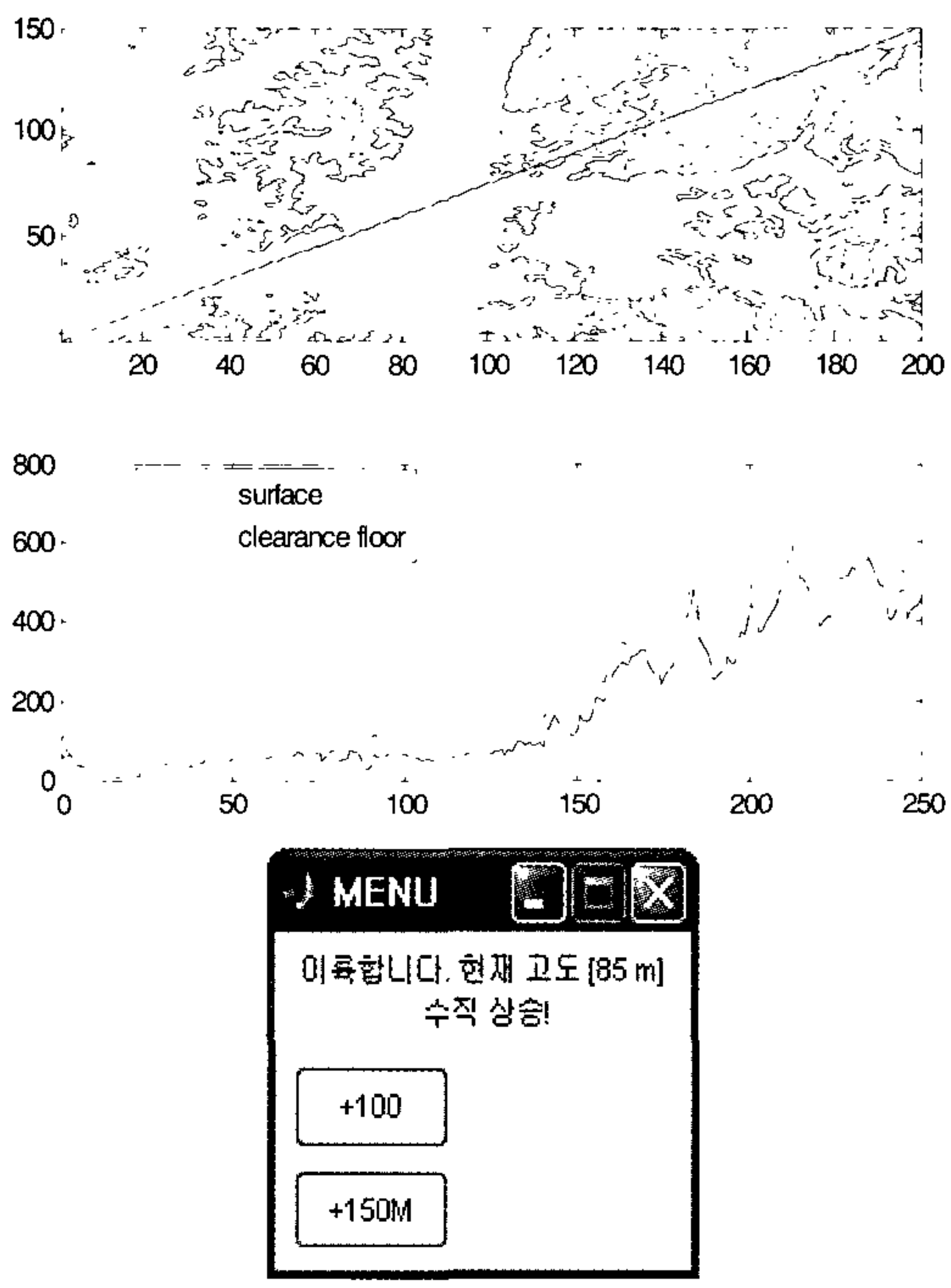

Figure 6. Display to pilot when departing from the origin

2) When navigating well

When navigating well, present position (x, y, z) of the helicopter is monitored on the contour map as well as on the profile as the Figure 7 without any message.

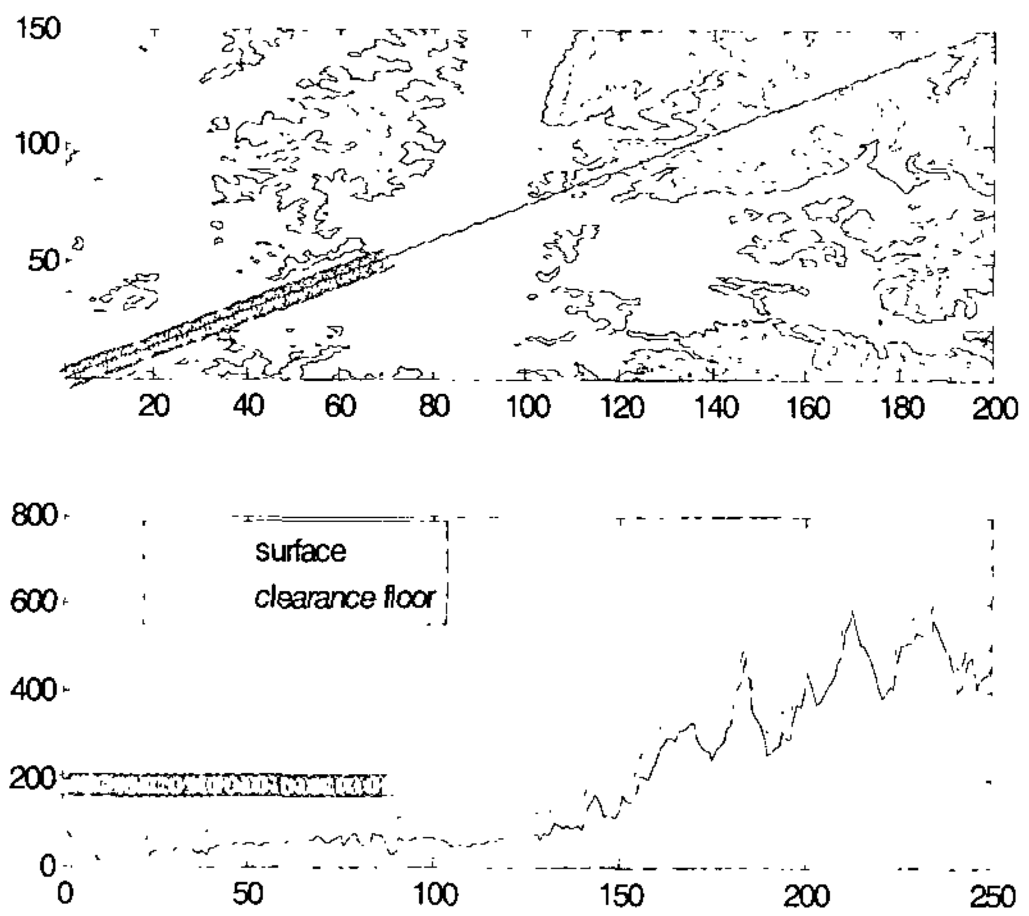

Figure 7. Display without warning message to pilot

3) When encountering the TCF

When the helicopter encounters TCF (210+50) m at (116,87,210) coordinates the warning message pops up with beeping sound as the Figure 8.

The warning message with the sound pops up whenever the helicopter encounters TCF during navigation.

4) When arriving above the destination

When the helicopter arrives at the position above destination (200,150,457) the menu which

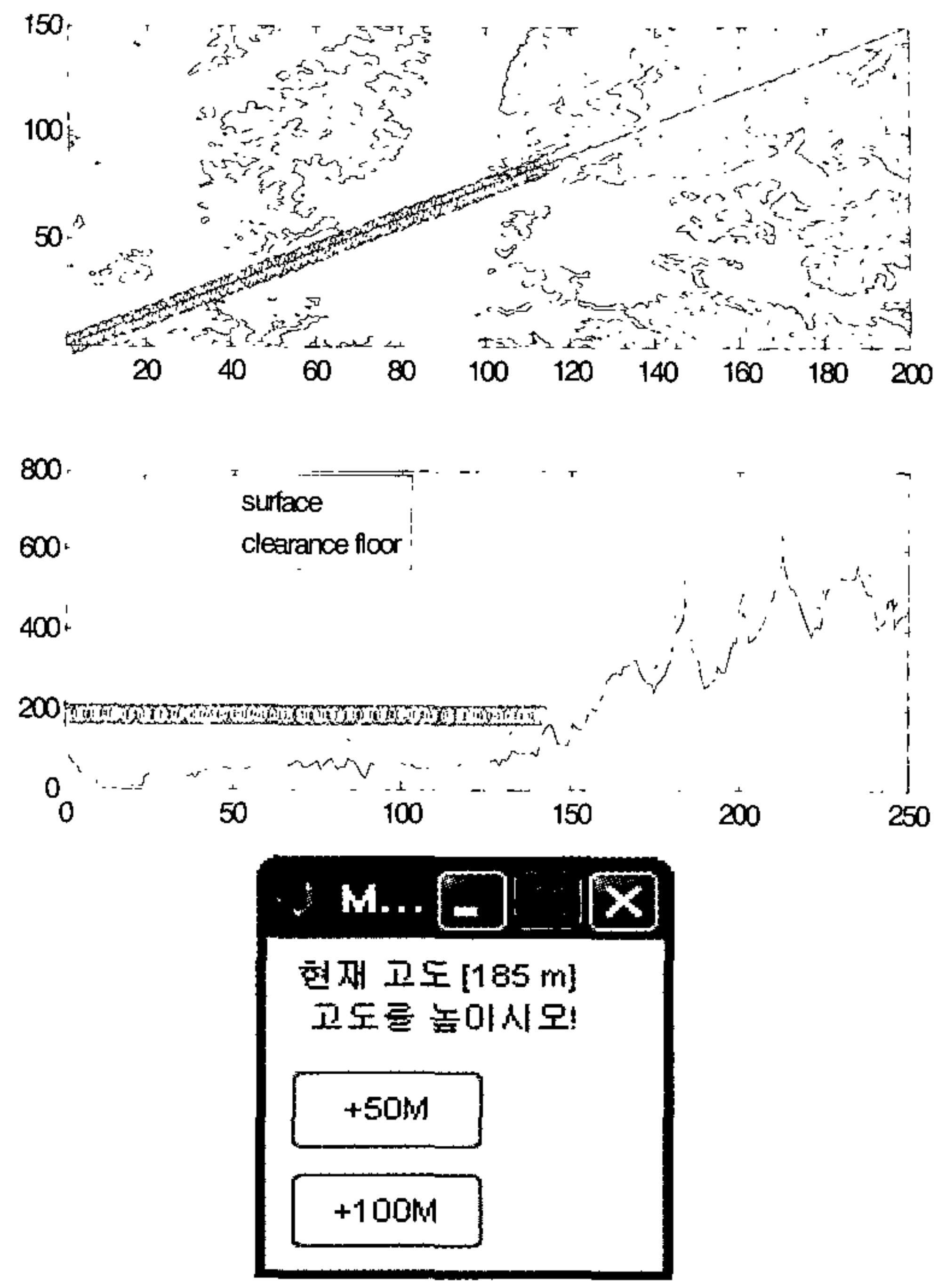

Figure 8. Display to pilot when encountering TCF

prompts vertical descending is repeated to pilot as the Figure 9. untill the Helicopter reaches the ground.

5) When the helicopter landed

When the helicopter lands on 457 m level of the ground safely, the final position and the message of arrival is displayed as the Figure 10. and the mission ends.

3. Concluding Remarks

The most fundamental information would be the view observed by the sight of the pilot.

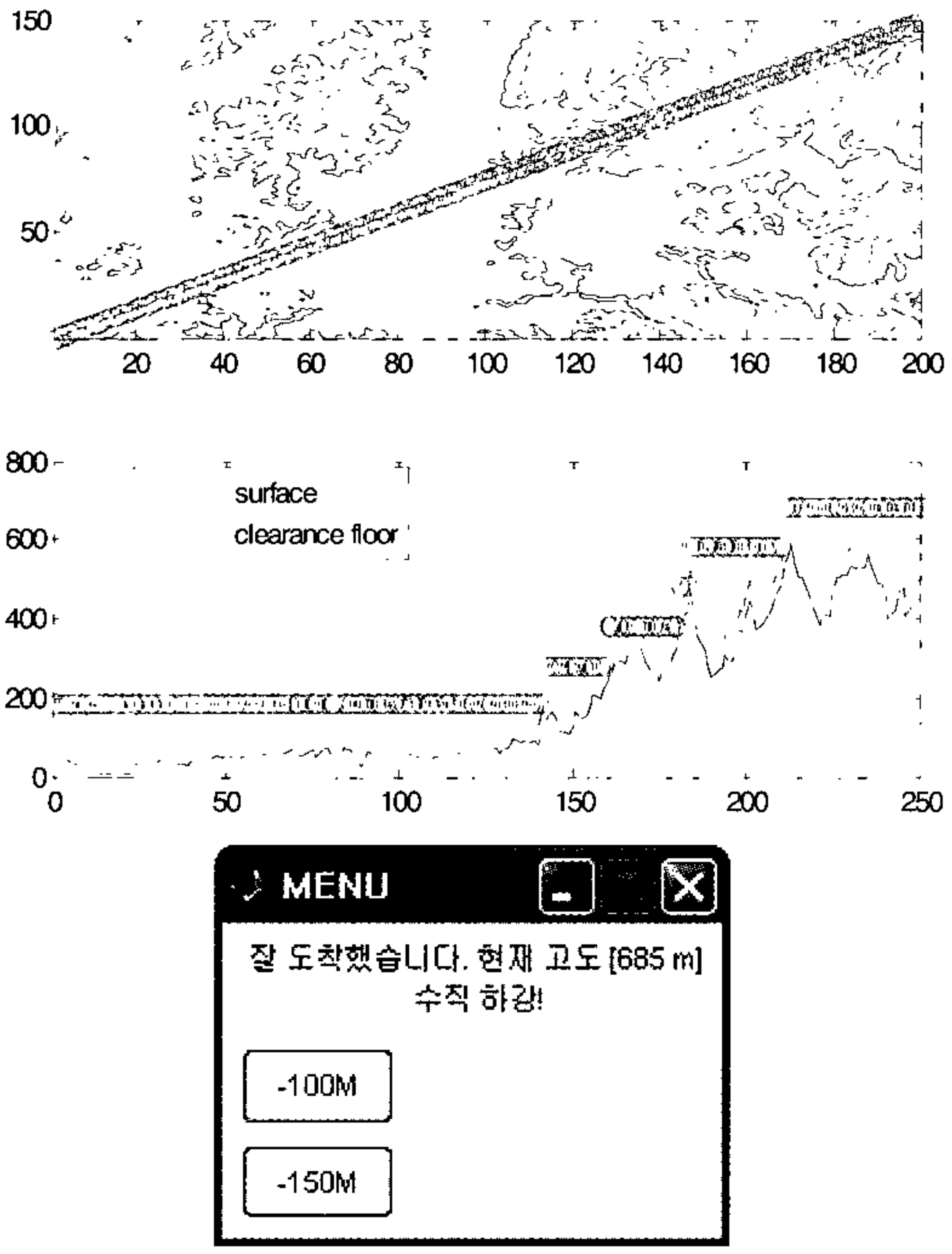

Figure 9. Display to pilot when arriving at destination

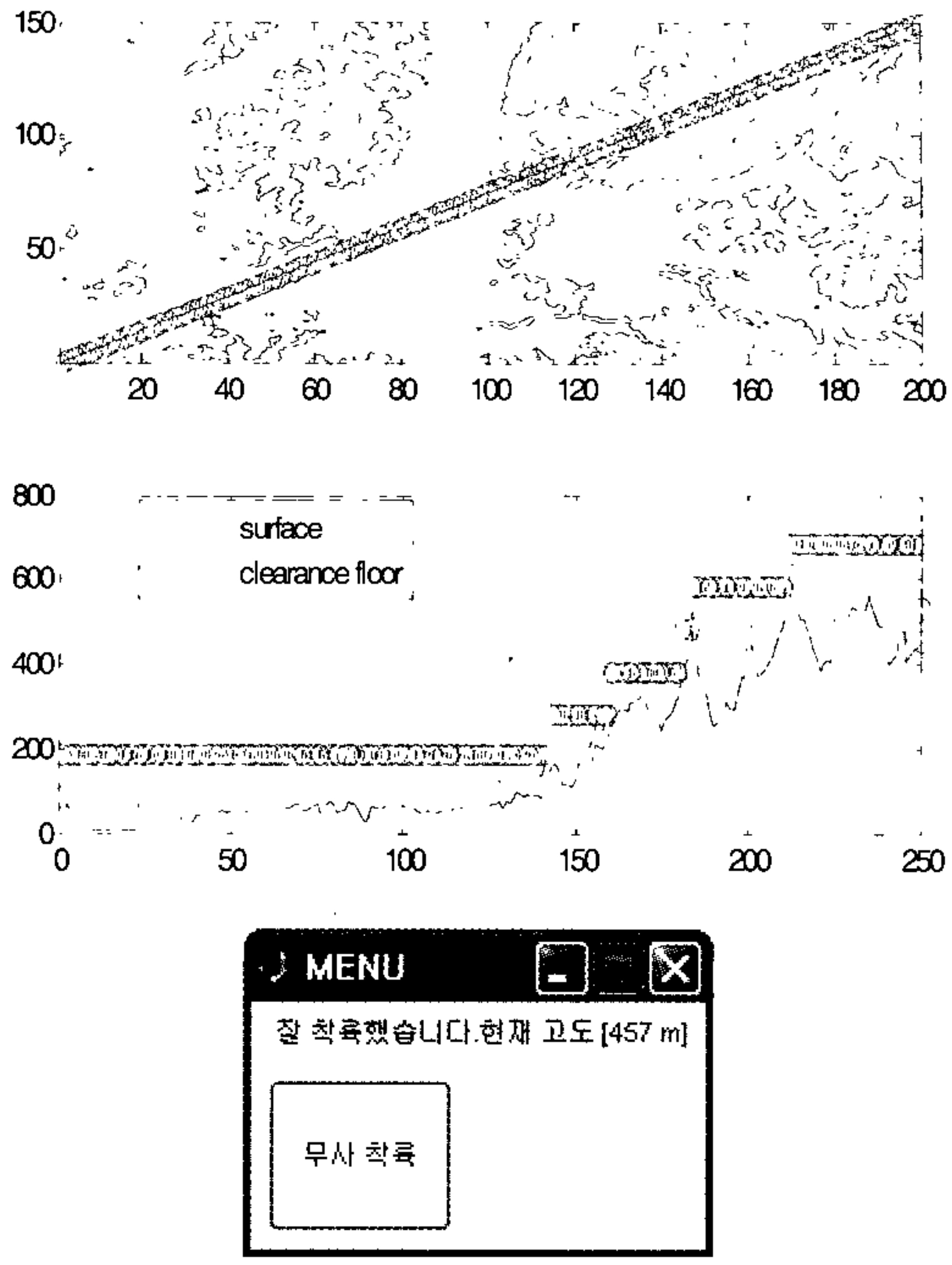

Figure 10. Display and message of safe landing to pilot

But the sight view might be uncertain in the area of complicated ground relief and even dangerous while encountering the bad weather particularly.

GCAS is utilized worldwide to guarantee the navigation safety but Korea yet.

The experiments of basic algorithm for 3-D helicopter navigation system on the basis of TRN (Terrain Referenced Navigation) with the assumption of information (x, y, z coordinates) input from GPS has been carried on.

In the present simulation, DTM (Digital Terrain Model) data of 3 seconds interval (about 92.8 m distance) instead of real time GPS data is assumed to be 1 unit time/distance interval.

The helicopter is assumed to have uniform horizontal velocity and vertical ascending/descending performance besides the flying velocity inertia of the other general aircrafts.

The velocity vector while navigating, exactly the speed and the direction of $V(p)=[v_x(p), v_y(p), v_z(p)]$ could be calculated in real time when the GPS is installed and the information input to this system is received directly. This experiments with performance test could be the next study.

The depth of buffer zone by TCF could be determined properly due to the purpose of actual navigation safety.

The present position of the navigating aircraft has to place its main reliance on the

INS/RadAlt unless on real time GPS data so as to compare aircraft z to TCF z referened by x,y coordinate from GPS.

The GCAS by GPS data input could be easily realized to practical use by simple installation of graphic interface between conventional GPS receiver and mission computer inside the helicopter.

The continuous study is much expected from the significance of simple but important interface, and from the standpoints of practical utility as well. In other words, the final objective of this study also lies at design of real-time operational navigation system of general flying vehicles all, including helicopter.

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