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The Design of Integrated Flying Vehicle Model for Engagement Analyses of Missiles

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ABSTRACT

High-Level Architecture(HLA)/Run-Time Infrastructure(RTI) are standards for distributed simulation systems and offer a technology to interconnect them and form one single simulation system. In defense domain, M&S is the only way to prove effectiveness of weapon systems except for Live Fire Testing (LFT). This paper focuses on guided missile simulations in weapon systems for engagement analyses and proposes the integrated flying vehicle model that is based on HLA/RTI. There are a lot of missiles in real world; therefore, we should develop each missile models in M&S in order to apply battlefield scenarios. To deal with the difficulties, in this paper, firstly, I classify these missiles into three models: ballastic, cruise, and surface-to-air missile models, and then I design each missile model and integrates them into a single model. This paper also offers a case study with my integrated flying vehicle model. At the conclusion, this paper presents contributions of this paper.

Key words: HLA, RTI, Guided Missile Simulation, Missile Model, Engagement Analysis

1. INTRODUCTION

In defense domain, obtaining effectiveness of weapon systems through M&S is the only way since Live Fire Testing is expensive in cost, time, and security. These days, weapon systems in M&S are interconnected using High-Level Architecture (HLA)/Run-Time Infrastructure (RTI)[1, 2], and heterogeneous simulators are composited into a single scenario[3, 4]. In past time, missiles are considered as a part of fire units in a certain platform. As missile systems are complicated and become expensive to develop, missile systems are recognized as an independent weapon system. In M&S, missile systems are a software model to generate trajectory data to a certain direction and to apply its location and posture into a battlefield scenario. There are a lot of missiles in real world such as purposes: defense and offense and types of projectiles: ballistic and cruise.

In this paper, I propose a single flying vehicle model that integrates different kinds of missile models for M&S. Finally, a specification of a target missile is inputted into the integrated missile model in order for the model to behave like the target missile upon HLA/RTI networks; therefore, developers for missile models do not have to consider the types of missiles anymore.

The remainder of this paper is organized as follows: In Section 2, this paper offers the research motivations; Section 3 provides missile models in M&S; In Section 4, this paper proposes the integrated flying vehicle model for engagement analysis. Section 5 presents a case study with my integrated missile model. Finally, Section 6 discusses my contributions of this paper and future works.

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2. RESEARCH MOTIVATION

M&S engineering is a huge process of solving problems using simulation with modeling techniques. It is a study for each steps of subjects arising in the process. In M&S, models cannot be presented in 100% of their target systems; however, systems takes abstraction process that will be fitted into M&S's purpose settled in advance[5]. Many models are created according to their M&S's purposes. For object-driven modeling, purpose-driven model developing methodology using Objective Performance Index(OPI) matrix[6] is used. Simulators are simulating algorithms or models efficiently based on modeling theories and implementing algorithms in a certain programming language. The algorithms in simulation models are developed in the shape of sequential/analytical/parallel program depending on computing environments or available resources[7]. For simulation composition, we need networking, database, Geographic Information System(GIS) with software techniques. Moreover, for interlocking among different kinds of model simulators, we should have protocol convertible techniques[8]. For model verifications, we test simulators by obtaining inputs from model specification and calculating their respondence, which is the same process with program debugging[9]. Model and simulator validations are a process that compares statistically equivalence of gathering data in real systems with respondence to simulation data[10].

Recently, performance engineering field[11] is closely worked with M&S. In statistically aspects, one simulation result indicates a same meaning with extracting one sample in a population that is built for statistical analyses if the performance measure processing is used for simulation model. In scholarly definition, a system is assembly of more than one subsystem (or component) that each subsystem has different functions and conducts a special function, usually it cannot conducted by a single component. There are many kinds of system components such as hardware, software, person(or operator), and bioware(or biological system). In real systems, there is the case that combined with same kinds of components. However, in general, system is combined with various kinds of components manifoldly. In my suggested model, the state is changing according to input and output value. This kinds of system are called 'Dynamic system'. Multi-Resolution modeling(MRM), the core technology complex and vast area simulation, expresses real system in another aspects[10].

There are two terminology definitions that I have interested in. One is simulation object model(SOM), or model, "A mathematical abstraction of the object's behavior that is usually instantiated in simulation source code" and the other is Multi-resolution simulation, "A simulation that involves models at different levels of resolutions." A single simulation object model (SOM) is sufficient to simulate system behavior in resolution level. Fig. 1. shows my conceptual model of the integrated missile model.

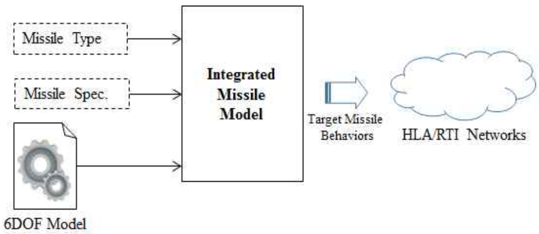


Fig. 1. My Approach.

3. MISSILE MODELS

There are many flying vehicle models. We can divide them into two groups. One is threat models such as aircraft model, cruise missile model, ground vehicle model, ship threat model etc. The other is the missile that shoots threats which can shoot threat component or threat missile. In this section, I explain several guided missile models that I used in my suggested model.

3.1 Ballastic Missile Model

"The Ballistic Missile(BM) Defense System is an integrated, layered architecture that provides multiple opportunities to destroy missiles and their warheads before they can reach their targets since ballistic missiles have different ranges, speeds, size and performance characteristics[17]." In M&S, BM model is generally composed in HLA/RTI networks as Fig. 2. This missile model become one of federators in HLA/RTI distribution simulation network. Simulator Controller transmits test scenarios and several parameters to BM Model through HLA/RTI network. Parameters, such as MissileInfo, MissileDetonation, SensorPos information are inputted into BM model in order to conduct simulation and send simulation result to HLA/RTI simulation network and GUI port.

In Fig. 2, MissileInfo includes message id, message length, missile id, missile type, flight phase, and missiles' position, velocity, acceleration in ECEF and NUE coordinate. MissileDetonation information contains missile id, crash state, missile position in ECEF coordinate, threat id, threat position in ECEF coordinate. SensorPos indicates threat position information.

In Fig. 3, the state of BM model is illustrated. The model operates by updating sensor's position data; namely, latitude, longitude, and attitude. The status of model are separated into two parts: Wait_State and Running_State. During simulation starts, transition stays in Wait_State and if the BM model receive fire signal, its transition movement to Running_State. After one BM missile fired, the next BM missile's transition is staying in Wait_State and this process is repeating continuously.

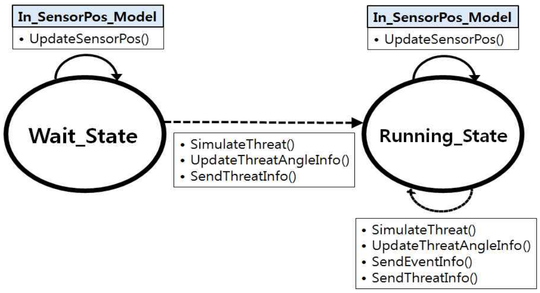


Fig. 3. State Machine in BM Model.

3.2 Cruise Missile Model

"Historically, the main attraction in cruise missiles(CM) has always been in the often very significant standoff range provided, keeping the delivery platform out of the reach of most if not all air defence weapons[18]." In M&S, CM model is composed like Fig. 4. as same as BM model. CM model become a federation member of HLA/RTI distribution simulation network. If Simulation Controller evokes and distributes scenario, CM model computes simulations using parameters from the input port MissileInfo, MissileDetonation, Sensor Pos that is similar to BM model. Finally, CM model sends simulation results to HLA/RTI simulation network and GUI port.

Input/output ports and their parameters of CM

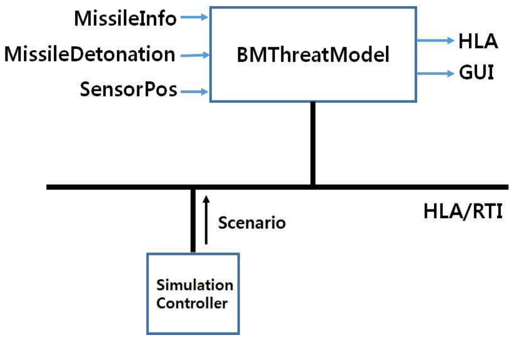


Fig. 2. Data Flow Diagram in BM Threat Model.

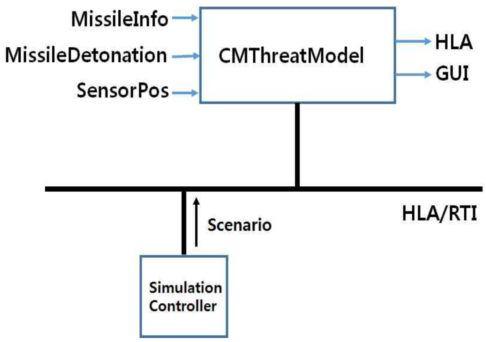


Fig. 4. Data Flow Diagram in CM Model.

model are similar to BM model; Several parameters of BM model are added but some parameters are slightly different. The different parameters between two models are as follows: Launch Point (LP) and Impact Point(IP) of BM model do not exist in CM model. Instead, CM model uses the position of launcher's standard and velocity for input data. In MissileInfo input port of CM model, the input parameters; namely, detonation flag and detonation state are added. In output parameters to HLA output port, dead reckoning algorithm and orientation parameters are added compared to BM model. Additionally, in the GUI output port, ground crash flag is added and damage status informations are transmitted.

Fig. 5. shows the state machine of CM model, and the state machine is very similar to BM model except for several parameters. The differences between BM and CM models are as follows: BM model receives LP and IP informations by determining input data before actual simulation. And it operates by updating 6 Degrees Of Freedom (6DOF) data continuously. However, CM model is operated in its waypoints regardless of LP and IP data.

Each of two models transmits missile ID, domain value, position, velocity, acceleration, position, detonation, identification information of our forces(or enemies) through HLA distribute networks. The transition in Wait_State goes to Running_State when missile firing as same as BM model. After firing present missile, transition moves to Wait_State of next missile.

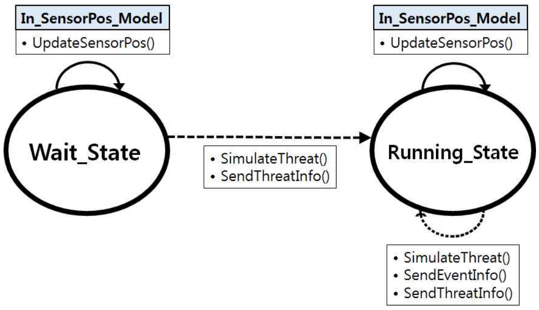


Fig. 5. State Machine in CM Model.

3.3 Surface-To-Air Missile Model

"A surface-to-air-missile(SAM), or ground-to-air- missile(GTAM), is a missile designed to be launched from the ground to destroy aircraft or othermissiles[19]." SAM model is interception missile that shoots down threat missile. In Fig. 6. SAM model transmits and receives various informations through HLA/RTI simulation network. SAM model simulator receives a test scenario and controls messages from Simulation Controller.

The control messages that Simulation Controller broadcasts includ a scenario distribution and simulation start/end control signal. SAM model also receives information about target missiles such as ID, position, and velocity from the threat missile simulator which is connected to BM or CM model.

In case that SAM model receives fire command message from fire control system which is connecting seperated network. If SAM simulator receives fire signal that fire control system operator transmits, SAM is firing against threat and simulator conducts threat shooting simulation. SAM model receives the following information from input ports and transmits those information to output ports as shown in Fig. 6.

- Weaponfire_HLA input port receives parameters of target missiles from a threat simulator.
- BattleEnv_HLA input port receives informa-

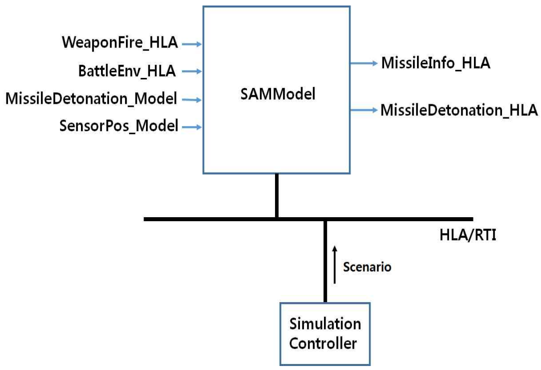


Fig. 6. Data Flow Diagram in SAM Model.

tion for battlefield environment containing geographic information.

- MissileDetonation_Model input port receives the information that SAM is encountered with the threat or not.
- SensorPos_Model input port receives position information for sensors.
- MissileInfo_HLA output port transmits information for SAM model and MIssileDetonation _HLA output port transmits detonation information of target missile to HLA/RTI distribution network.

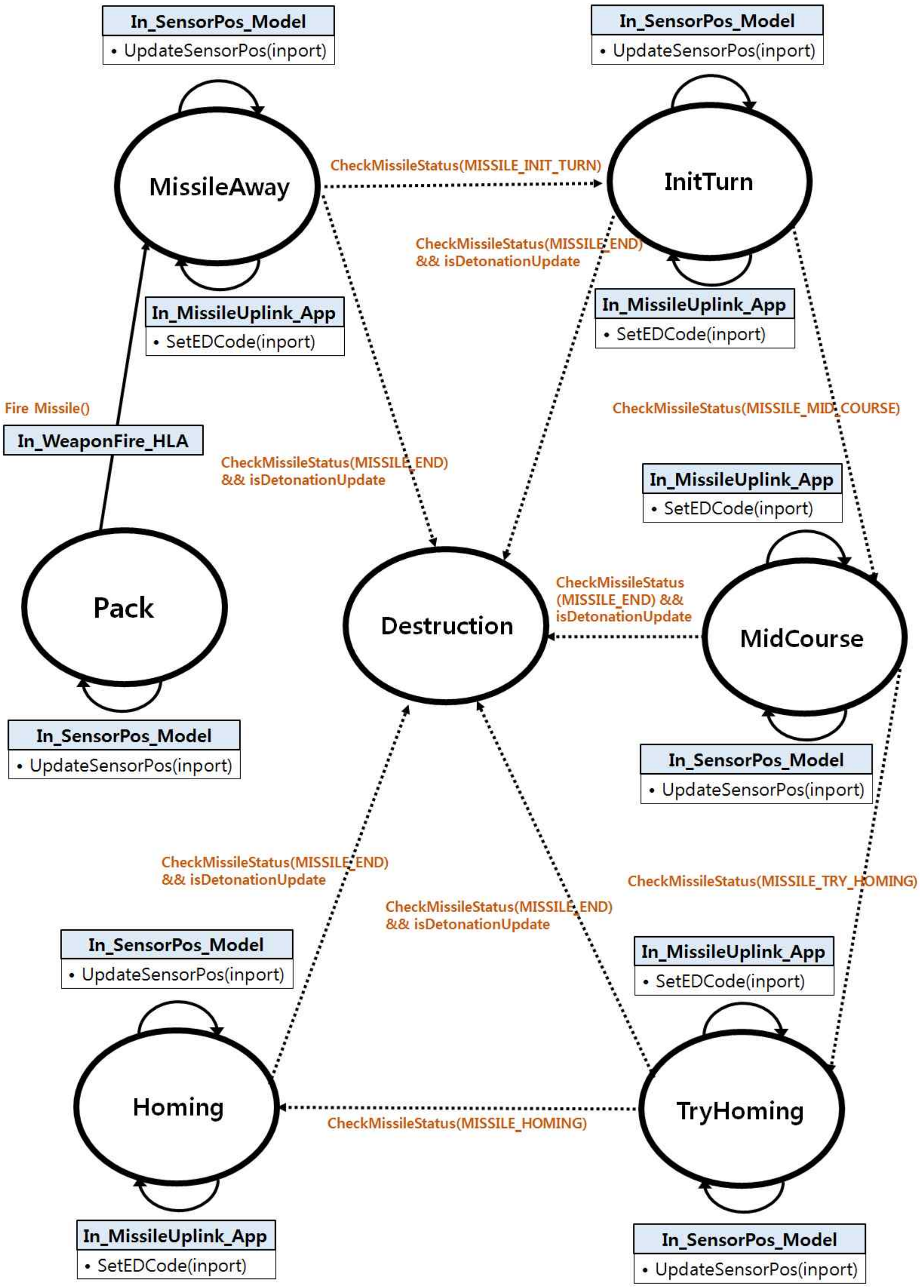


Fig. 7. State Machine in SAM Model.

The state machine of SAM is described in Fig. 7. First, a state 'Pack' indicates that the guided missile is inserted into launcher in order to be ready to fire. If guided missile receive fire signal, a transition occurs to 'Missile Away'. The 'Missile Away' state points out the guided missile is fired. Missile flies with receiving targets' ID, number, positions(X,Y,Z), velocities(Vx,Vy,Vz), accelerations (Ax,Ay,Az), and LP data updated continuously in air defense simulation. After missile away, the guided missile's state goes to a 'InitTurn' state.

Guided missile starts flying to IP in 'InitTurn' state and if inside status of guidance missile be the middle lead flight state, the state of guided missile be 'MidCourse'. When SAM flies from 'InitTurn' state to 'MidCourse' state, it generates trajectory data until it detonated.

When a threat comes into detecting area in seeker view, the missile's state changes to 'Try Homing' and the guided missile tries to closeout tracking of a threat. In 'Homing' state, the guided missile conducts closeout tracking continuously receiving the recently updated threat data. If the guided missile detonated by certain reason, the missile's transition goes to 'Destruction' state.

In this state, the guided missile is destructed and stopped its flight. The guided missile can be destructed after running into the threat. Otherwise, all states' transition except 'Pack' state can be changed into 'Destruction' state by terrain collision or due to operator corruption.

4. THE INTEGRATED MISSILE MODEL

In this section, the integrated model is proposed. Fig. 8. illustrates the data flow diagram of proposed model. BM, CM, and SAM models as I described the previous section are combined into one model. The input ports of this model are designed as MissileInfo, MissileDetonation, and SensorPos parameters that are for BM/CM models. This model has weapon fire, battle environment, missile detonation input port for SAM model. This model also

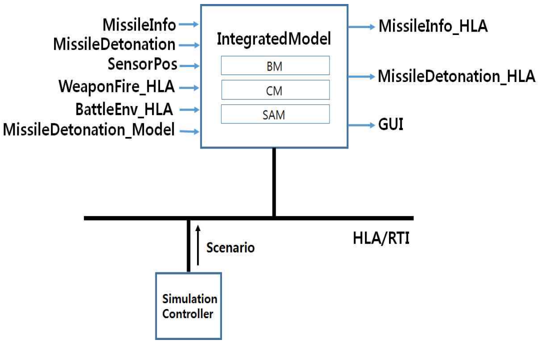


Fig. 8. Data Flow Diagram in the Integrated Model.

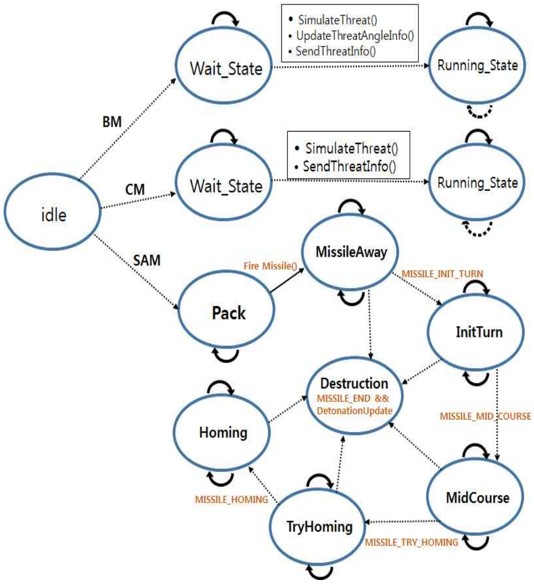


Fig. 9. State Machine in the Integrated Model.

computes simulations inserting input parameters to BM, CM, and SAM submodels and finally it transmits a simulation result to HLA port and GUI port.

Fig. 9. shows the state machine of the integrated model. Every BM and CM threat models and SAM model are merged into one 'idle' state. Every transition stays in 'idle' state and waits the signal that which missile is launched. If certain missile is launched, transition moves to correspond state and conduct each missile's mission. Each missile's work is as similar as I described in section 3.

The following section conducts a small case study in order to compare and analyze flight trajectory data between my integrated model and independent BM/CM/SAM models in a simple battlefield.

5. SIMULATION RESULT

In this section, the result of simulation test applying various missile models to BM, CM, and SAM will be discussed. In this simulation, I plan to compare the missile trajectory data applying single missile models and integrated missile model. The horizontal axis indicates time durations of simulation, and each vertical axis is latitude, longitude and altitude. For the measurement units, the latitude and longitude are indicated by degree and altitude is indicated by meter in every graph. And I assumed that there is no detonation caused by emergency explosions in administrators or terrain collisions.

5.1 Scenario composition

Fig. 10. shows the scenario in my simulation designed by fire controller. In Fig. 10, The starting point of every objects' routes indicate LP(Launch point) and the stopping point after missile flying and making trajectory indicates IP(Impact Point). The scenario is composed of one BM missile, one CM missile and several SAM missiles. For the comparison of each missile trajectory data from single models and integrated model, I applied the same scenario to each simulation in order to compare the result in the same environment.

5.2 Simulation test result

Firstly, Fig. 11. shows two trajectory data in BM model and my suggested integrated model. In Fig. 11, latitude of both BM model and integrated model are decreased, and both longitudes are increased as I established BM route in the scenario. In altitude value, both BM model and integrated model go up around 90 km. In all figures of Fig. 11, some gaps between BM model and integrated model are illustrated.

Fig. 12. indicates two trajectory data in CM model and integrated model. In Fig. 10 scenario, we can know both latitude and longitude degrees of CM model and integrated model are decrease.

Fig. 13. shows SAM trajectory data comparing BM model and integrated model that targets BM threat. In Fig. 13, SAM's latitude in both two mod-

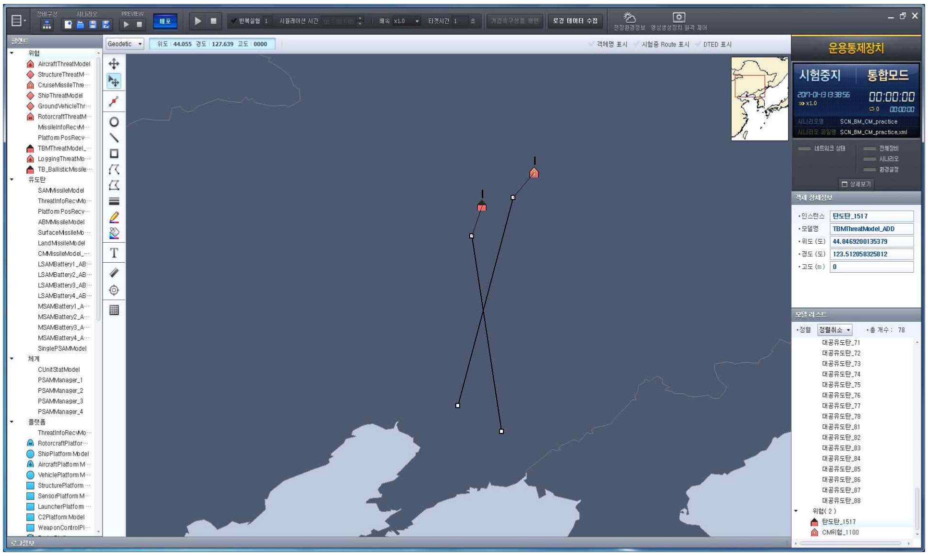
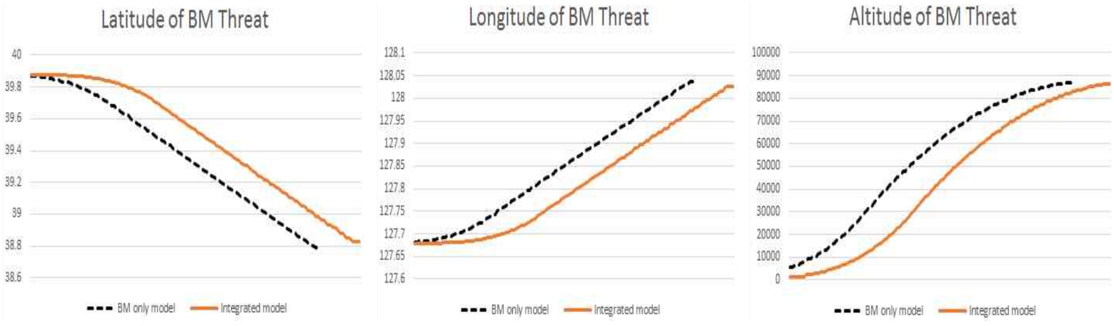
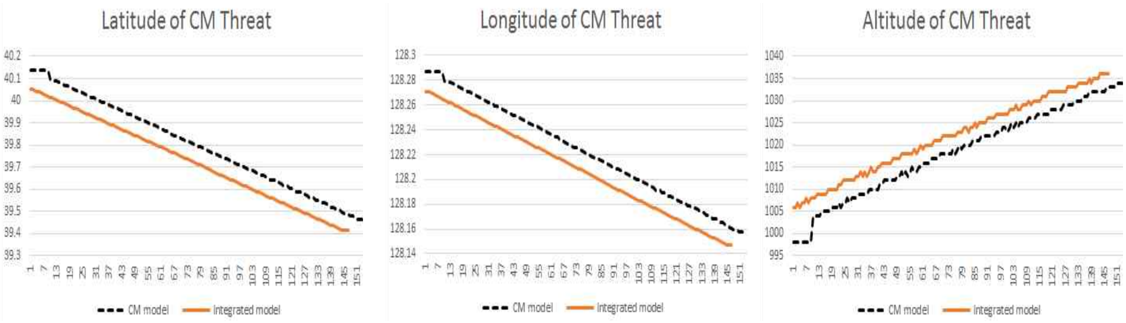


Fig. 10. Scenario.



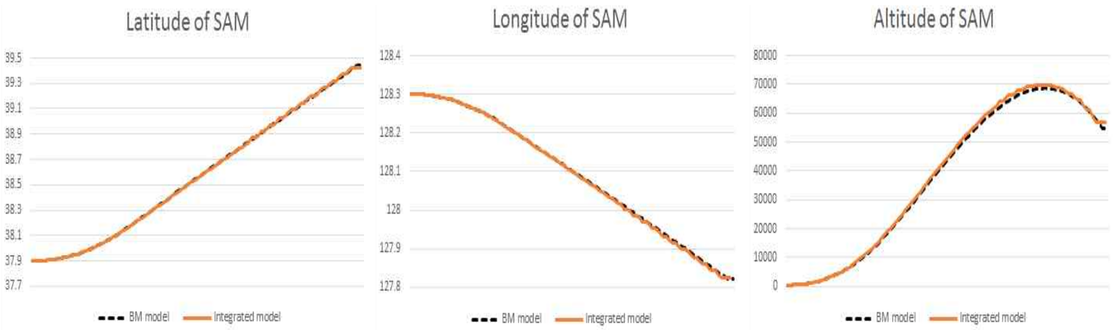
(a) (b) (c)

Fig. 11. Trajectory of BM threat, (a) Latitude (b) Longitude and (c) Altitude.



(a) (b) (c)

Fig. 12. Trajectory of CM threat, (a) Latitude (b) Longitude and (c) Altitude.



(a) (b) (c)

Fig. 13. Trajectory of SAM shooting BM threat, (a) Latitude (b) Longitude and (c) Altitude.

els are increased but longitude are decreased. By this two factors, we can imagine two SAMs fly up from south-east to north-west ways for shooting two threats BM and CM. Also, we can know SAM detonated BM threat around altitude 55km not that before it reaching the maximum point but that it starting falling down.

6. CONCLUSION AND LESSON LEARNED

In this paper, I proposed the integrated flying vehicle model, a network based missile model, combining several independent missile models together. Under the networked environments, I discovered advantages as follows:

• We can develop missile models independently even though in physically remote places since these systems are based on network.

• The system based on frameworks, there are much advantages. Above all, this framework based system is good for flexibility, scalability and maintaining homeostasis by extending guided missile models and simulators freely. And we can correct or change the guided missile model easily. Because this kind of framework system shares many same interfaces, we can applicate various guided missile models to basic frame easily. Also, this system is useful to compose interconnected environments.

• Even though each model developers have different software coding style, various developers can cooperate together. Every developers should implement the model by the regular frame unit. By this reason, though anyone who did not develop model by themselves can understand other's implementation and cooperate easily. Either, even if this kind of system looks as if consume much time on the beginning of constructing framework, finally we can shorten total development time. After building base framework, we can applicate many kinds of guided missile models by using same infra.

However, there exist several weakness points either, as follows:

• Missile model developers are restricted for parallel programming in engineering level simulations.

• We completely exclude simulation delays due to the simulation environments; namely, waiting process time and network delays.

• It is impossible to verify missile model objectively.

• There are limitation on simultaneous operating in different scenarios.

• There are several weakness points caused by frame based either. In this kind of structures, prior to changing or new constructing to original frame, we need basic framework acknowledgement vitally. Without this, we cannot take advantageous as I mentioned before. Also, in systems, it is very complicate that all interfaces of every frames are connected each other. Because of this, if one interface has wrong connection this can lead to all simulation stop. So we must concentrate to connection of each frames' interface. Either, like in this kind of system, the base frame is very important. If there are some error in base frame, it is inconvenient to find and to correct that we have to explore every frame to find fault part from the top to bottom step. If we ignore this problem, this can be cause of stop working model simulation operating. Furthermore, it is difficult to construct new frame work on the existing legacy stack established long time ago.

For the future work, firstly, I plan to do the research on suggested guided missile models being applicate to various real equipments. And I will try to apply real guided missile model, using present time, to my suggested model. Secondly, I will focus on another kind of various threat models and missile models to my proposed model. Lastly, I will take an effort to develop guided missile model using 6DOF data and that can reflect much more realistic environments.

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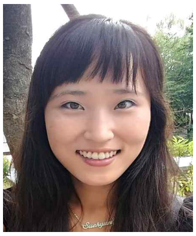

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