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A FLIGHT SIMULATOR FOR TESTING OF ACTIVE INCEPTOR TACTILE CUES FOR FLY-BY-WIRE AIRCRAFT

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ABSTRACT

A simulator for fly-by-wire aerial vehicles is built for studying active inceptors, tactile cueing methods, testing the applicability of combining tactile cueing methods with developed envelope protection algorithms. The simulator is built around the active inceptor which is used as a side stick. X-plane is used for visuals while the setup could be arranged both for fixed-wing and rotary-wing platforms. This can be simply done by running a different flight model and changing the between throttle and collective controls. The simulator environment demonstrated to be viable setting for incorporating an active inceptor to envelope protection studies.

INTRODUCTION

Fly-by-Wire (FBW) technology replaces mechanical connections between the pilot control devices and control surfaces with electrical cables [P.G. Hamel, 2017]. With the introduction of FBW, passive inceptors became the default controller. This somewhat disconnects the pilot from the aircraft as there aren't any direct feedback through the inceptor as in conventional mechanical controls. Simply an artificial feel can be created with the use of spring and additional masses which simulates the direct link to the control surfaces. However, artificial feel can also be simulated using sensors and servomotors that provide the "tactile information" about the aircraft behavior. These "cues" can be especially important in flight critical regimes such as stalled flight conditions [P.G. Hamel, 2017]. Such devices which feel is created with servomotors are called "Active Inceptors".

The main difference between active and passive inceptors is that in active inceptors, the flow of data becomes duplex. Pilot's physical inputs are transmitted to the aircrafts actuators while the FBW system gives dynamic feedback to the pilot through the active inceptor via tactile cues.

With the introduction of these active inceptors, many possibilities in pilot-control interaction has emerged. These are mainly centered around changing the characteristics of the stick in flight for cueing. As this a relatively new topic, extensive research should be made to explore robustness and potential issues of these systems before applying to aircraft. Hardware-in-the-loop and human-in-the-loop simulations are a proper and convenient environment for such researches. With this purpose, the simulator environment presented in this paper is

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established. The simulator focuses around the active inceptor by providing a capable environment for testing envelope protection algorithms with different tactile cueing methods. With its modular design, both fixed-wing and rotary-wing aircraft simulations can be made.

SIMULATION ENVIRONMENT

The simulator environment consists of an active inceptor, Flight Link Advanced Helicopter Package [Flight Link, 2019], Saitek pilot controllers [Saitek, 2019] and two desktop computers (Figure 1). Computers run on Windows operating systems with Nvidia GTX770 graphic cards (Two in Computer 2). Flight Link Advanced Helicopter Package consists of a cyclic, collective, pedals and a pilot seat. Saitek pilot controllers comprise of a stick and throttle. The throttle controller from Saitek and the collective from Flight Link are used interchangeably for different flight models, namely for fixed-wing and rotary-wing models. The active inceptor is used as a side stick for both control stick and cyclic purposes.

Figure 1: Simulation environment

Active Inceptor

Active inceptors are pilot controls which replace the spring and dampers of traditional control systems with programmable electric motors. As these motors are programmable, not only passive feel can be given but also the force characteristics of the stick can be changed on the fly to give feedback actively to the pilot. This ability is the main difference between active and passive inceptors. The data flow between the pilot and controller is bidirectional in active inceptor cases compared to the single directional data flow from pilot to controller in passive inceptors. The data flow comparison of active and passive inceptors can be seen in Figure 2.

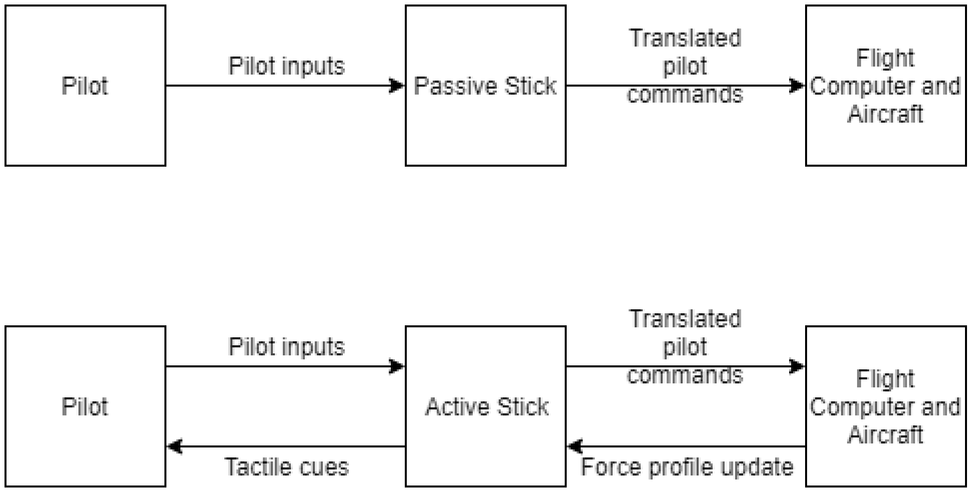

Figure 2. Data flow comparison of active and passive inceptors.

Some of the different usages of active inceptors can be listed as below:

- Imitating forces on mechanical connections between control surfaces and control stick so the pilot can feel hinge moments,
- Electronically coupling of control sticks in aircraft with pilots for informing pilots of each other and pilot training purposes,
- Mechanical jams, control surface loss simulations for training purposes
- Tactile cues for limit avoidance and pilot workload reduction.

For the active inceptor a Stirling Dynamics Next Generation Inceptor is used (Figure 3). The features of this inceptor allow numerous configurations, namely the properties given above. In this work, the emphasize is given on tactile cues. The cues can be set for warning the pilot about approaching aircraft limits or even prevent the pilot from passing them. Stick shakers, hard and soft stops can be examples for such cues. In the simulator shown here, an estimation method called “Direct Adaptive Limit and Control Margin Estimation with Concurrent Learning” [G. Gürsoy, 2016] is implemented around the flight model to detect approaching envelope limits. This method is used to estimate the control margins which are the available control travel to reach limit boundaries. These estimated control margins are than used to form desired tactile cues by inputting corresponding force values and stick angles to the active inceptor. As an example of a force profile for stick, variable gradient hard stop profile with respect to control margins can be seen in Figure 4.

Figure 3: Stirling Dynamics Next Generation Inceptor

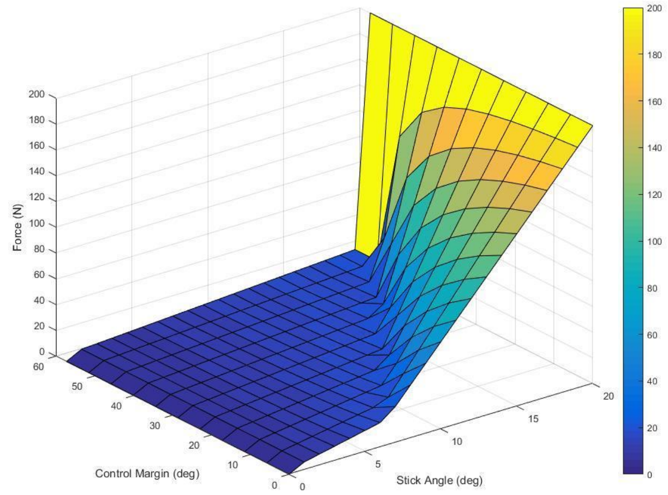

Figure 4: Variable gradient hard stop force profile with respect to control margins

Simulation Setup

The simulator is set for two main configurations. One configuration is for rotary-wing while the other is for fixed-wing simulations. By simply swapping the collective and throttle the aircraft configuration of the simulator setup can be changed. This makes a time and cost-effective simulator environment for different platforms as most of the parts are used mutually between configurations.

Rotary-Wing Configuration

In the rotary-wing configuration, two computers are connected to each other with TCP/IP connections. Flight Link controllers are connected to Computer 2 while Saitek controllers are connected to Computer 1, both with USB connection. The active inceptor is connected to Computer 1 through UDP.

Computer 1 runs the simulation controller (SMC), Simulink model and multi-function display (MFD). On Computer 2, the flight model and X-Plane runs. SMC controls the simulator by initialize and start/stop options. It also shows if the connections between hardware and software components established correctly. With the input from pilot controls, the flight model calculates the aircraft states and then sends them to X-Plane for visualization and Computer 1. Through Computer 1 the MFD and Simulink model is fed. The flight model gets the Flight Link inputs over Computer 2 while pilot inputs from the active inceptor is from the Simulink model. Flight Link cyclic, active inceptor and Saitek stick can all be used and each case all of them can override each other. The configuration used here is Stirling active stick and Flight Link pedals and collective for rotary-wing configurations, and Stirling active stick, Flight Link pedals and Saitek throttle for fixed wing configurations.

The Simulink model allows running the envelope protection algorithms and feeding the outcomes to the active inceptor and flight model through S-functions. One S-function is for the flight model so it can run simultaneously with the flight model on Computer 2. The other S-function is for communicating with the active inceptor. The flow chart of the simulation setup can be seen in Figure 5.

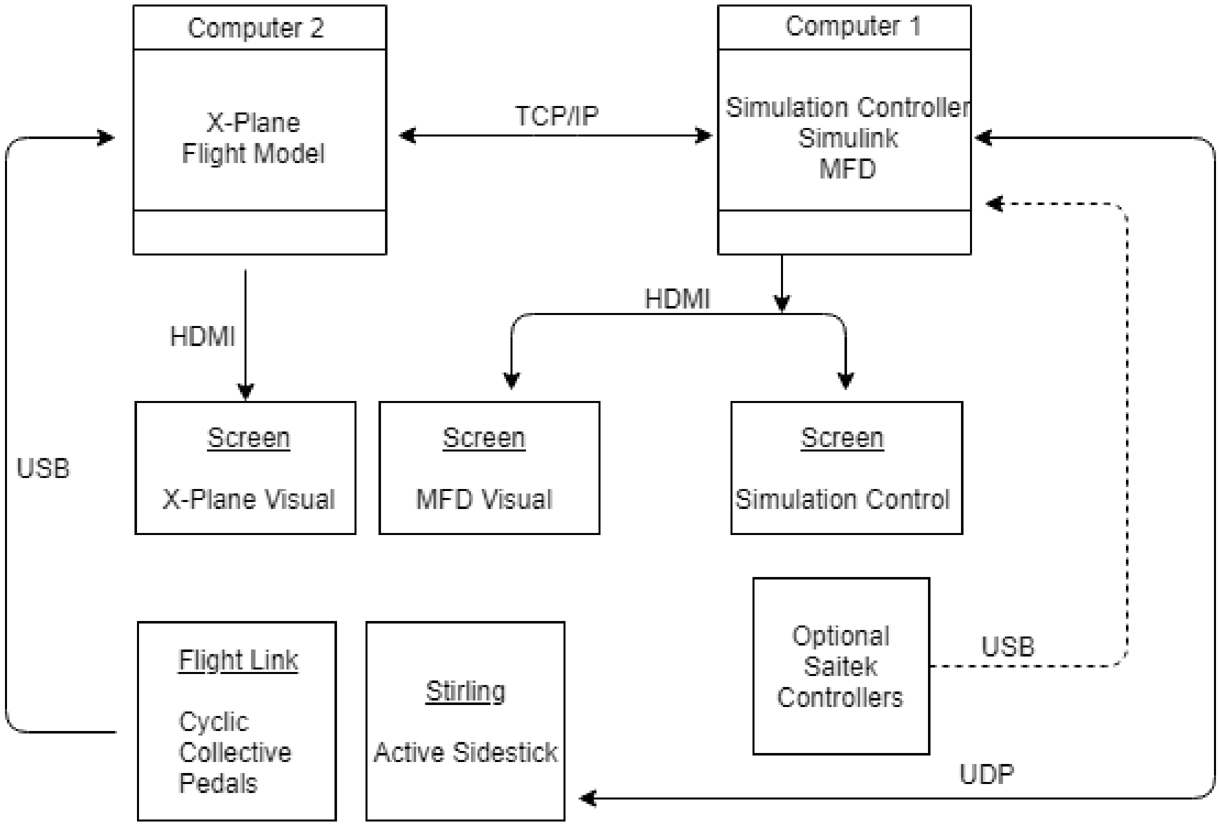

Figure 5: Rotary-wing simulation environment flow chart

Fixed-Wing Configuration

For this configuration, Flight Gear is used for visuals and flight model runs on directly on Simulink. So, this configuration is able to use only one computer, Computer 1. The connection of Saitek controllers and active inceptor remains the same as the other configuration. As only Computer 1 is used in the fixed-wing setup, Flight Link controllers are connected to it, instead of Computer 2. The flight model runs on Simulink and aircraft states are sent to Flight Gear for visualization. Also, these states are fed back to the Simulink model which runs the envelope protection algorithm and active stick controller. The desired outcomes of the active stick controller send the necessary information to the inceptor through a S-function. As the rotary-wing case; the cyclic, active inceptor and Saitek stick can override each other. For this configuration the main controls are set as, active inceptor, Flight Link pedals and Saitek throttle. Flow chart of this configuration is given in Figure 6.

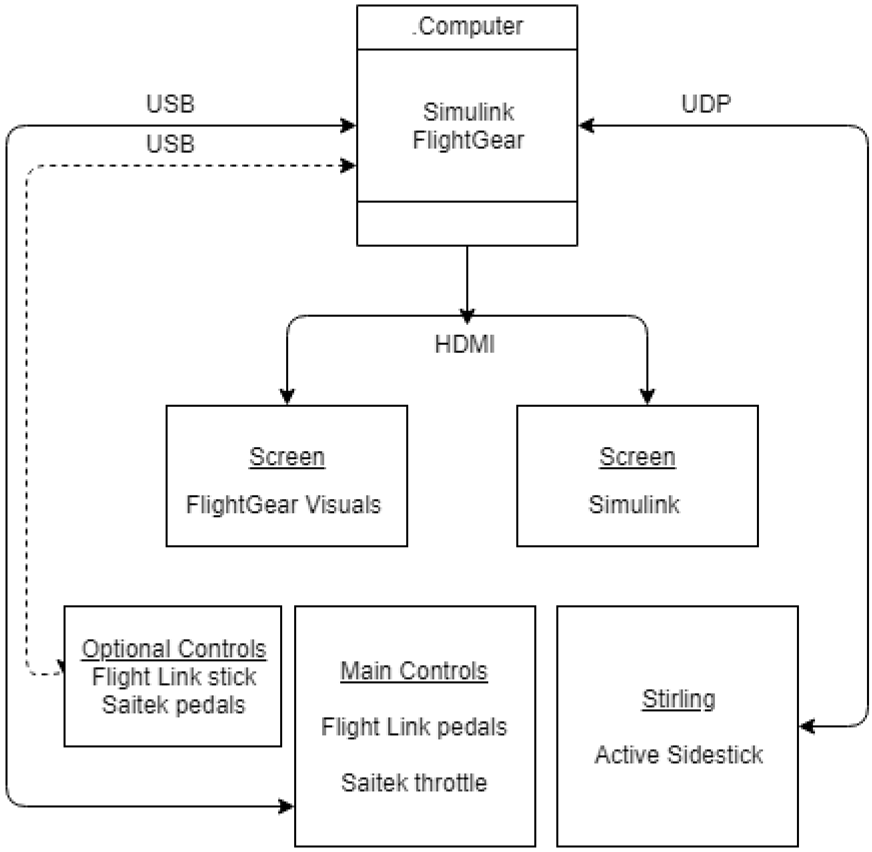

Figure 6. Fixed-wing simulation environment flow chart.

PILOTED TESTS

Piloted tests are made to examine the suitability of the simulation environment for future tests. Three Turkish Army Aviation pilots with different experiences participated in this phase. The flight hours of the pilots can be seen in Table 1.

	Single Engine Fixed-Wing	Two Engine Fixed-Wing	Rotor-Wing	Total Flight Hours
Pilot 1	600	0	1050	1650
Pilot 2	600	1800	250	2650
Pilot 3	100	250	150	500

Table 1. Flight experiences of pilots participated in tests.

With initial trials, the force characteristics of the passive mode is tuned. The tuned force profile can be seen in Figure 7. There are apparent differences in pitch and roll axes. The roll axis of the inceptor has less range and required force per degree. The reason for this is the anatomy of human wrists. The maximum degree a person can turn a wrist left and right are different. Thus, the maximum range in roll is limited compared to pitch axis. Also, the maximum force which can be applied by turning the wrists are much less compared to pulling and pushing which is the reason the force gradient tuning process converged to a smaller required force per degree in the roll axis.

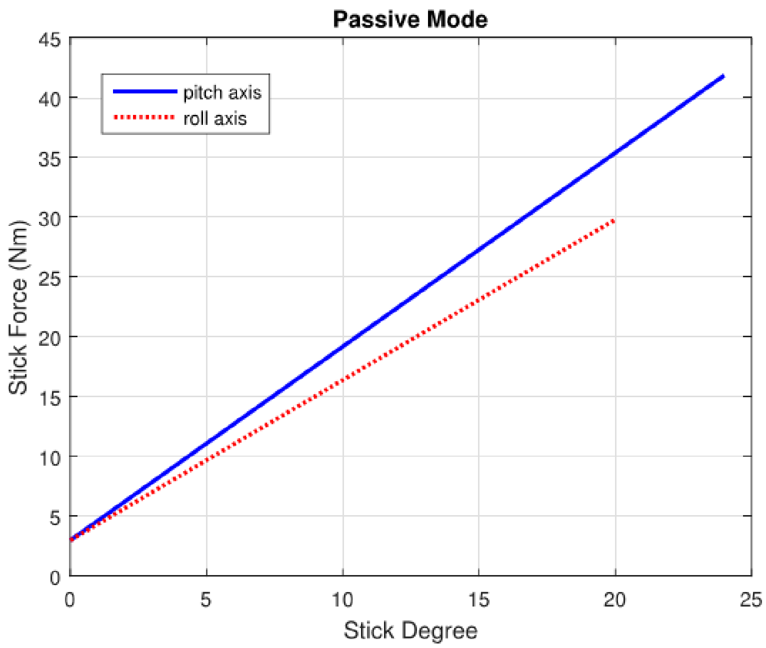

Figure 7. Passive mode force profile of the inceptor.

Tests were made in order to check the effectiveness of some tactile cueing methods coupled with the “Direct Adaptive Limit and Control Margin Estimation with Concurrent Learning” algorithm. In Figure 8 and 9 two examples of such cases of an aggressive turning maneuver are given. In Figure 8, hard stop tactile cueing method is used. In hard stops, the inceptor prohibits the pilot to move the stick in the limit exceeding direction on limit boundaries. Here from the figure, it can seen that the hard stop effectively prevented limit exceedance for both angle-of-attack and normal load limits. In Figure 9, a soft stop is used as the cueing method. Soft stops initially prohibit movement of the stick in limit exceeding direction but with the application of enough force, the pilot can pass these limits. This allows full control over the aircraft while still warning the pilot about limit boundaries. This is the case in Figure 9, where the cue initially stops the pilot from passing angle-of-attack limits. But the pilot decides to intentionally pass this limit around 21 seconds.

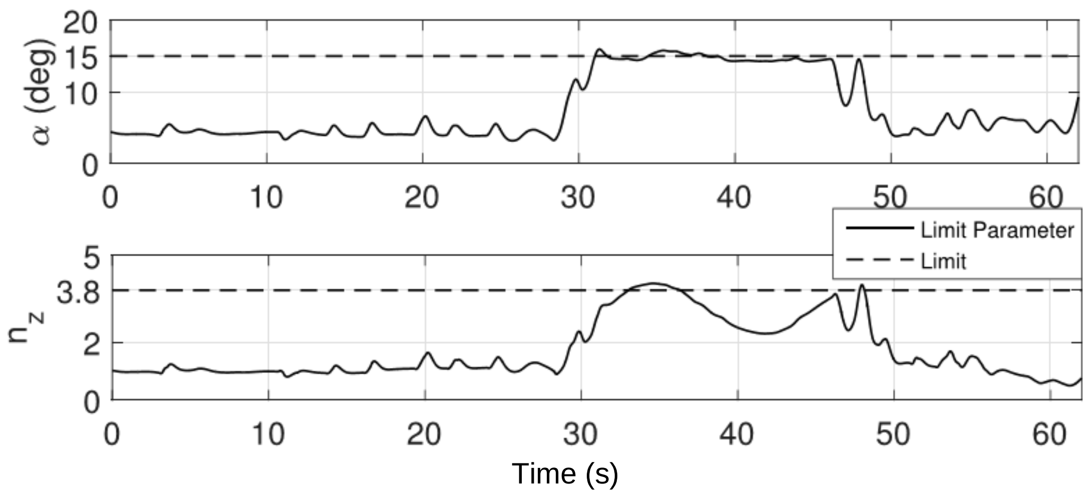

Figure 8. Testing of hard stop cueing.

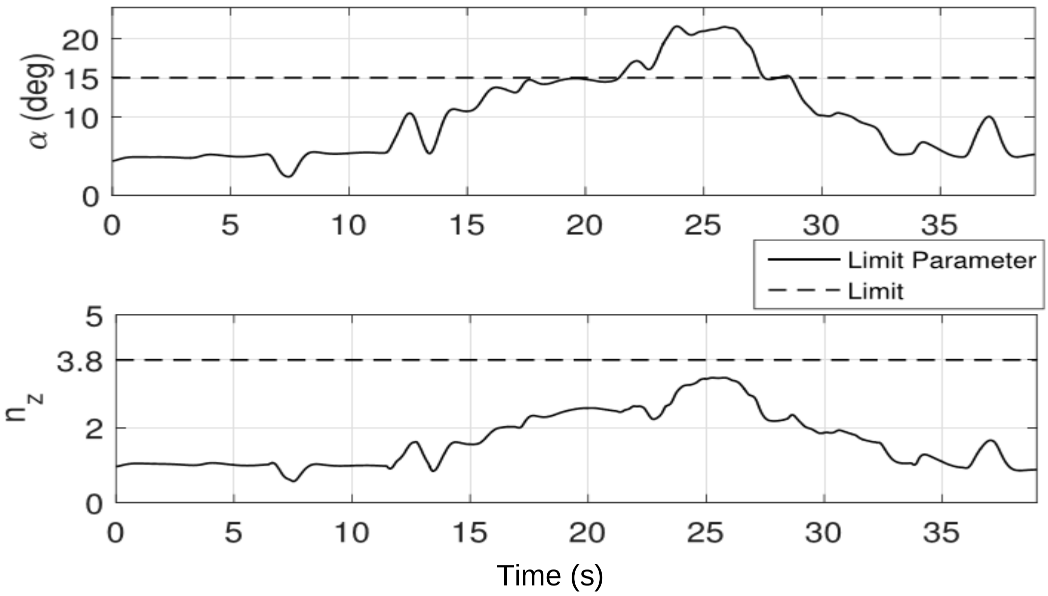

Figure 9. Testing of soft stop cueing.

CONCLUSIONS

A simulation environment around an active inceptor is built for tests on both fixed-wing and rotary-wing platforms. Through the Simulink and flight model connection, a basis for envelope protection algorithm development is established and with the active inceptor a testbed for tactile cues is achieved. Test flights are made with pilots and the default force profile for the passive mode is tuned. During the tests, envelope protection with tactile cues proved to be viable as limit avoidance is achieved via a hard and soft stop in an aggressive maneuver. With this environment Middle East Technical University gained the capability for developing envelope protection methods, tactile cues and testing these via active inceptors.

References

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