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Evaluation of Inceptor Design for Manned Multicopter

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Abstract—In aviation a very narrow spectrum of control inceptors exists, namely centre-sticks, side-sticks, pedals and yokes. However, new types of aircraft are emerging and with them a need for new inceptors. A manned multicopter created at AGH University of Science and Technology is an aircraft in which the pilot takes a specific orientation in which classical inceptors may be impractical to use. In this paper unique kind of control inceptor is described, which aims to provide a handling quality not unlike standard solutions and provide a firm grip point for the pilot without the risk of involuntary stick movement. Simulations of pilot-inceptor model were performed in order to compare dynamic amplification factors of design described in this paper with classical one. Functional prototype is built on which drone pilots carried out a comfort of use evaluation. This paper provides a general overview of the project, including literature review, reasoning behind components selection and mechanism design finalized by conclusions.

Keywords—Mechanisms, mechatronics, embedded control, serious gaming, rescue missions, rescue robotics.

I. INTRODUCTION

DURING last few years, the popularity of drones is still high after recent growth. They are used in the fields of photography, cartography, sports races and military aims. A new branch of their usage is delivery or even personal transportation, meaning moving an individual person from one place to another. In case of manned constructions, the term “multicopter” is better, because the name “manned drone” is against the idea of drone. At present, there are only a few of this kind constructions. One of them is "T.S.O. - Manned Drone" project, which is being created at AGH University of Science and Technology (Fig. 1). It is a manned multicopter designed to carry one person. It could be used in purposes to i.e. rescue people from inaccessible areas. One of key design assumptions of this project is that pilot will be positioned nearly horizontally, similarly to sport motorcycle rider. It is supposed to give him/her better view both forward and below the machine. At the phase of preparing a concept it was determined that because of specific orientation of pilot it will be required to design a new kind of inceptors.

In the scientific literature there are no descriptions of inceptors optimised in terms of: firstly, risk of involuntary inceptor movement caused by aircraft acceleration and secondly, making the inceptor a firm grip point for a pilot. However there are some works considering force feedback inceptors focused e.g. telepresence joystick [1]. and car steering joystick [2]. Many of these publications concern mainly control algorithms but hardly ever construction particulars. The authors pay a lot of attention to force feedback inceptor control algorithms in usage with flight simulator [3]. One of the interesting projects is the joystick created by German Space Agency [1], because of its unique construction solutions. As a linkage between stick axis and motors shaft a capstan reduction was used, stick construction was based on Cardan mechanism (more of potentially useful details are not available). Described device has been used on International Space Station so it must have met high standards.

Fig. 1 T.S.O. project early rendering

In the domain of helicopter steering [4] is particularly interesting one. It researches influence of different configurations of inceptors on handling quality (a few sticks with different numbers of Degrees of Freedom and different mappings were analysed). The conclusions are as follows: firstly on simulated helicopter flight during nap-of-the-earth task pilots preferred low deflection side-stick (± 5.3° or ± 8.3°), rather than stiff stick, secondly, with good peripheral visual cues pilots preferred standard set of pedals, side-stick and collective lever or 3-axis stick. 4-axis stick received good notes only in specific conditions. Its low performance is believed to be caused by cross-coupling between axes. There are some publications studying influence of stick length on control quality and comfort, e.g. [5]. Experiments were conducted with participation of crane operators performing tasks on two levels of difficulty. It was determined that operators performance increased when using short joystick with high gain.

Works [6, 7, 8] are important ones in domain of pilot modelling. This field is particularly important to this work because good pilot model could be used to simulate dangerous effects which may arise during flight. There are some models designed to simulate roll-ratcheting, however they are limited

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to simulating effects of rotation in one axis and does not have chance of working well in other situations. Basic workflow when designing pilot model is to create a parametric model, then we perform an identification (it is difficult to create universal model). The fact that parameters values could not represent real values is another factor diminishing trustworthiness of these models, it happens even if model's response has high level of consistency with experimental data.

II. ELECTRICAL COMPONENTS

Electrical circuit should have following functions:

- converting sticks orientation to electrical signal;
- interpreting electrical signals;
- performing communication with flight simulator and multicopter's onboard flight control system.

To fulfil these requirements optical encoders and a microcontroller were chosen as main elements of the system.

A. Position Transducers

In industrial joysticks most frequently potentiometers and Hall effect sensors are used as an angle transducers. Another possible, though less common, choice is the use of optical encoders. They are present especially when force feedback is implemented [1, 3]. Despite their rarity in joysticks and other inceptors, it was decided to use optical encoders in construction because of their robustness - in the environment in which they will operate, they may be exposed to interference and vibrations from motors. Project assumptions are met by PIB3806-2000-G5-24-C optical encoders, they were used in project.

B. Microcontroller

In order to process electrical signals from encoders STM32F103 microcontroller was chosen. It has four hardware timers able to work in two-phase mode designed specifically for encoders. Many other features are present such as possibility to be configured as HID class USB device and number of interfaces (CAN, UART, etc.). These qualities make STM32F103 capable of being used in conjunction with flight simulator and flight control system.

C. Program

Program running on microcontroller is minimalistic, it performs a few basic functions. Thanks to STM32Cube IDE it was possible to easily configure the microcontroller as HID class USB device. Because of that it could be effortlessly connected to majority of flight simulators. In the main loop values of counters are being mapped to values between -1 and 1, then HID report is formed and sent to PC. Of course interfacing with buttons and other as well as communication with a flight control system elements is possible but these functions have not yet been implemented as not relevant to the proof of concept.

III. MECHANICAL DESIGN

It was hypothesized that a stick that rotates relative to the axes passing through it at the point where it is grasped could provide a handling quality not unlike standard solutions and provide a firm grip point for the pilot. Proposed mechanism is a chain of three links connected in two kinematic pairs. Connection between link 1 and base is a revolute joint as well as connection between link 1 and link 2. Rotation axes of these joints intersect at right angle regardless of position of the links. The pilot leaning on the stick will not cause it to rotate without a deliberate movement of the wrist thanks to such mechanism structure. Project development proceeded iteratively – a few prototypes were created using 3D printing technology with Fused Filament Fabrication method. This allowed to determine unknowns created at the design stage that were impossible to verify with simulations and calculations, and provided valuable information from potential pilots on usage convenience. Final prototype (Fig. 3) is fully functional device capable of controlling simulated drone, it is also possible to easily connect it to the multicopter's flight control system. Whole set of inceptors (Fig. 3) consists of two sticks (as in Fig. 2). This kind of axes separation should resemble one known to drone pilots from radio transmitters. In such devices four 2-DoF sticks are present controlling respectively: one pitch and roll and the other throttle and yaw. The same axis mapping should provide short learning time for drone pilots.

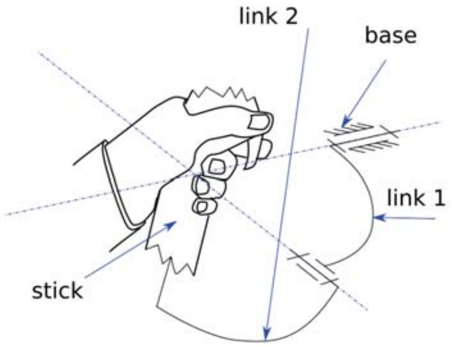

Fig. 2 Kinematic structure of proposed inceptor

IV. TESTS

To assure that design assumptions were met, a number of tests were performed, including dynamic simulations of pilot-aircraft system and evaluation of comfort of use by pilots controlling a drone in a flight simulator.

A. Dynamic Simulations

An abstract of simulation process is presented further, full description of performed analyses should be published separately.

In order to correctly simulate behaviour of the pilot-aircraft system a well-prepared pilot model is required. Existing pilot models were designed to be used in highly specific situations.

Fig. 3 Final prototype

This fact and other after-mentioned negative aspects do not make them helpful to this work. Lack of good enough existing models made it necessary to design a new one. Pilot model "Gerwazy" was designed, it consists of rigid bodies connected with joints in such a way to resemble the upper part of a human body. Masses and lengths of rigid bodies are set to values corresponding with average real values. Joints connecting rigid bodies possess adequate number of degree of freedom, stiffness and damping factors. One serious shortcoming of this model is lack of proved source of stiffness and damping factors, they were set to arbitrary values that provide realistic behaviour of the model. In further works an identification of these parameters, using 6-DoF platform should be carried out. Performed simulations should be treated as a proof of concept rather than an evidence.

Configuration of a simulation is as follows:

- model of a system was implemented with a Simscape Multibody addon in Simulink environment;
- motion of a virtual 6-DoF platform is an input of the system;
- pilot model is connected to the 6-DoF platform with a torso;
- investigated stick is connected to pilot model's hand;
- investigated stick axes movement is output of the system.

Dynamic amplification factors were calculated for range of frequencies (0.01 Hz to 100 Hz) for translation as well as rotation in every axis (Figs. 4 and 5). Results are promising - in majority of tested cases dynamic amplification factors generated for proposed inceptor are lower than these for classical stick.

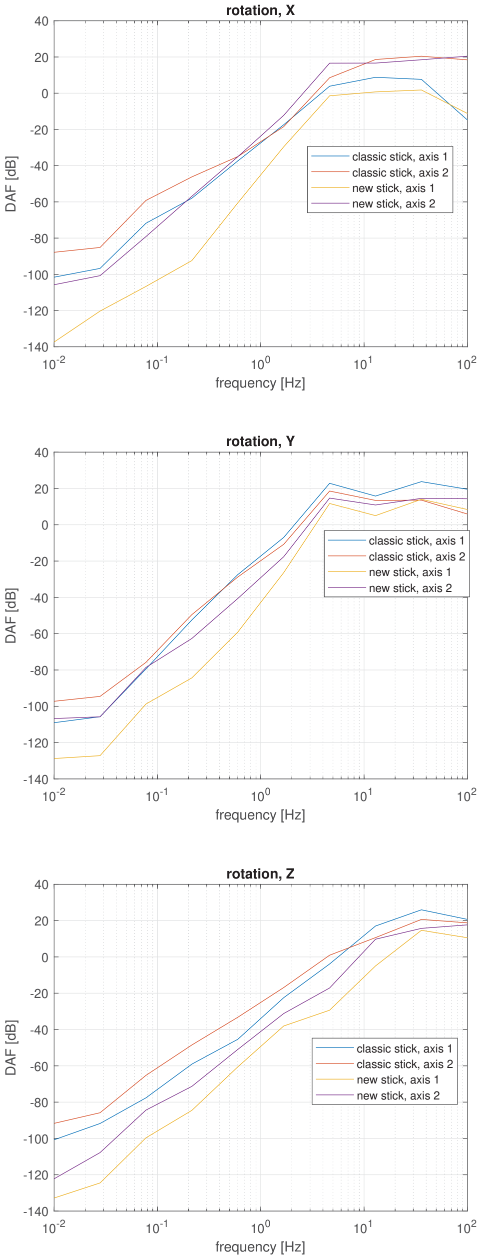

Fig. 4 Dynamic amplification factors (rotation)

B. Experimental Evaluation by Pilots

A series of tests were carried out which evaluated comfort of use by pilots controlling a drone in a flight simulator. Aim of these tests was to compare two inceptors: one described in this work and a classic joystick – Logitech Extreme 3D Pro (3-axis joystick with throttle lever). Pilots were volunteers on different level of experience, their task was to complete a race in Drone Racing League flight simulator. Best times and comments of pilots were noted. The order of which stick came first was random to eliminate bias for pilots with short experience. Test program was as follows:

- max 30 min to get used to every inceptor;
- 15 min for time-measured flights for one inceptor and another 15 min for the second one;
- noting best times, completion of the survey.

In the survey following aspects were measured:

- drone pilots experience;
- inceptors evaluation in terms of: easiness of drone control, impact on hand fatigue, subjective achievable manoeuvrability;
- comparison of best times from both devices.

Ten volunteers attended in tests, it is a small number,

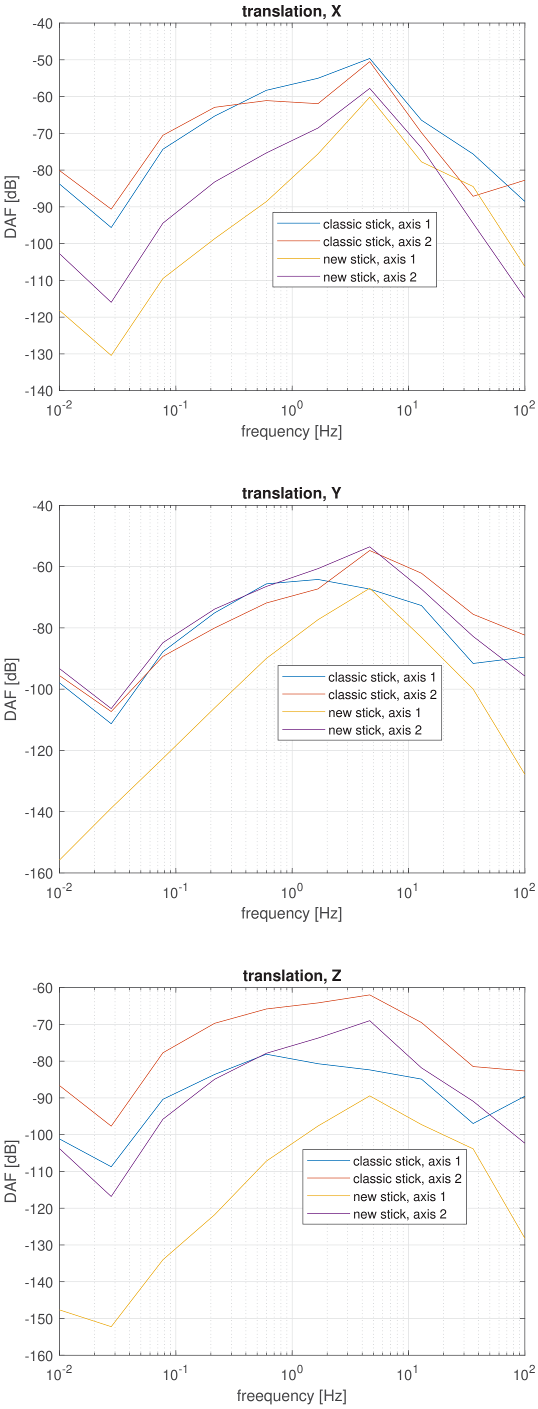

Fig. 5 Dynamic amplification factors (translation)

nevertheless results are presented. The times obtained on the inceptor described in this study were slightly longer (Fig. 7), however it not a main objective of this device. New inceptor was rated as having slightly less impact on hand fatigue than the classic one (fig. 6). It seems that the rest of the studied features are comparable for both devices (Figs. 8 and 9). The survey left space for volunteers' comments. Due to their extensiveness, they will not be quoted here but only summarized:

- The classic stick was judged more intuitive, experienced pilots, however, saw the analogy with drone radio transmitter and had no problems mastering the experimental stick,
- Volunteers noticed a few problems like the width of the stick spacing and the range of motion of axes, and agreed that with these changes (simple to make) the prototype would benefit a lot,
- Pilots noted that the drone controlled by the experimental inceptor seems larger and heavier, and that they reduce the possibility of accidental movements.

V. CONCLUSIONS

Tests with volunteers have established that the manipulators are competitive with classic sticks, and even may be better in some aspects. They are judged to have less impact on hand fatigue than the classic stick, and they also meet the premise of providing a firm grip point for the pilot. The flight times for the classic stick were on average several seconds shorter, the median of the relative differences between the times was about 15%, the times from pilot to pilot varied widely. Testing the inceptors in the environment for which they were intended was beyond the author's capabilities, but it was possible to run a number of simulations. Mathematical model of the pilot based on real proportions and masses of body parts was created and used to determine the dynamic amplification factors from the virtual 6-axis platform to the sticks. Due to the lack of solid data (stiffness coefficients) for the pilot model, this should be treated as a proof of concept rather than an evidence of the validity of the hypothesis that the design described here is better than classical ones. In further research, it would be advisable to conduct an identification of a model on a 6-axis platform.

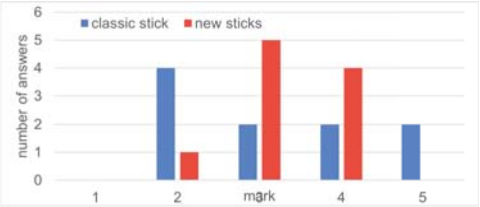

Fig. 6 Subjective impact on hand fatigue (1-high impact)

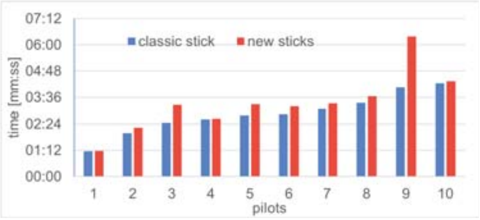

Fig. 7 Best noted times

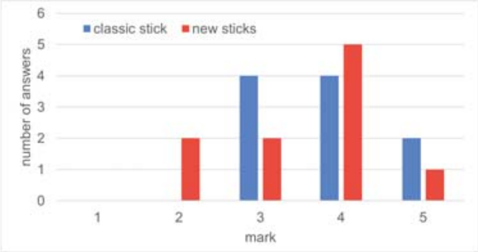

Fig. 8 Perceived easiness of drone control (5 - high)

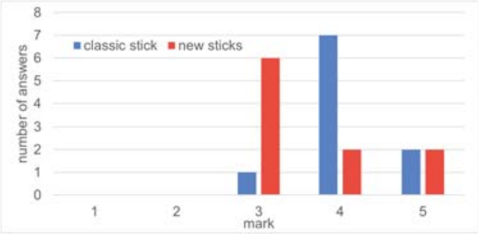

Fig. 9 Subjective maneuverability of drone (5 - high)

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