Designing of Automatic Control System for Camera Crane Based on PID controller and Inertial Measurement Unit

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Abstract. This paper presents the designing of automatic control system in real-time for vertical and horizontal motion control of camera crane. The traditional camera crane manual control system has some control problems. To meet this, unifying proportional integral derivative (PID) controller with precision Inertial Measurement Unit (IMU) on main board STM32 control were implemented. The mathematical calculations were approved by the results of experimental tests and confirmed by the correct functioning of the processing algorithm and the operation of the system as a whole. Camera crane has 3 axes.

Keywords: Automatic control system, embedded system programming, control laws, PID control, inertial measurement unit, real-time, microcontroller.

1 Introduction

Filmmaking and other applications for action shooting traditionally use the crane, which should move dynamically in inertial coordinates. The crane is used with 3-axis camera putting on it, as shown on Fig.1. The speed range and motion directions of camera crane as usually manually controlled by operator.

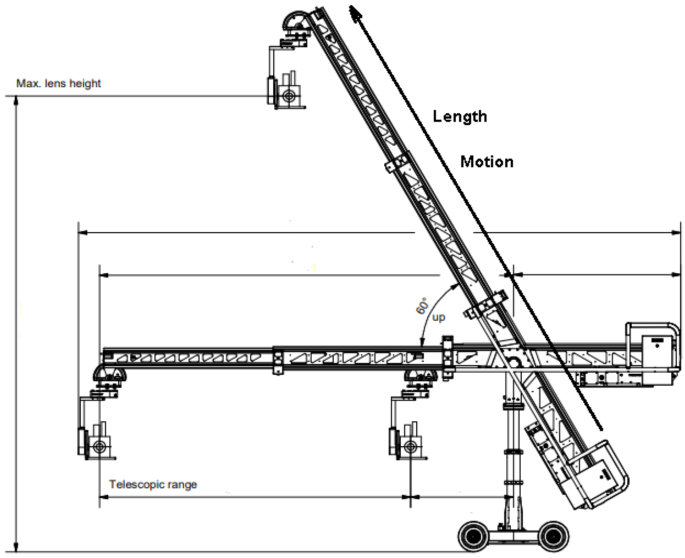

Fig.1. Crane structure and camera crane kinematics

Most of camera crane`s control systems are designed with manual control board, PID controller, rotation mechanism and could operate in manual or semi-automatic operation mode [1]. To control the camera crane operator has to pre-select the speed range on the hand control. In manual mode motion directions are calculated according to the length of the camera crane. It means that operator has to check the present conditions (sensor settings), to compare it with the desired value (processing) and to take appropriate action in order to obtain the desired value (actuator).

This is the simplest way to control camera crane. However, it`s leading to malfunctions in the control system and collisions in communication channel and requires further manual fixing. To avoid these problems and to achieve enough accuracy, reliability and high-speed automatic control systems developed [2-3].

2 Control system

The main task is to design a precision automatic control system and make the possibility to switch on the manual mode. In this case, control system requires a powerful main board, like STM32F7 Discovery, 32-bit ARM Cortex-M core-based microcontroller programmed in C++ Cube IDE [4]. This board controls electronics and mechanics by processing algorithm and visualizes crane camera motion in real time by drawing two moving axes on integrated LCD display.

To control the motion process according to given specifications, connected in a circuit, fed the desired value or conditions and thereby controls the process to maintain the desired values of motion parameters. The advantage of this process is that no human intervention is required. Also, the rate of the process is uniform.

Control system (Fig.2) has two absolute encoders to rotate motors. They have output codes that allows to determine current position, but cannot be transmitted to program code. For this task we used STM32103 board. It has a special interface designed for processing data coming from the encoder. Depending on it, the value of the counting register increases or decreases to determine the side on which the rotation was and indicate the next direction.

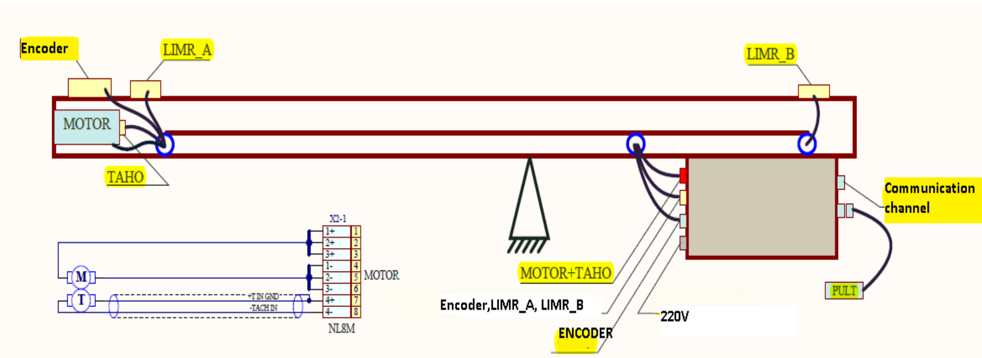

Fig.2. Control system with encoders

Regardless of the control mode, the work begins with a manual control board (pult). In manual control mode it is necessary to track the encoders, because over time there are failures and errors in the rotation system occur. Encoder is the rotation angle sensor for motors to control trolley motion (LIMR_A) and camera crane position (LIMR_B). The quick, sensitive controls avoid distracting start-up rocking motions, which is an advantage that is not to be underestimated as opposed to other drive concepts. To increase the accuracy, the inertial measurement unit (IMU) is integrated to the motion control system.

IMU is a self-contained sensor that measures linear and angular motion usually with a triad of gyroscopes and triad of accelerometers that allows make measurement in 3 axes: pitch, roll, yaw with high precision. An IMU can either be gimballed or strap down, outputting the integrating quantities of angular velocity and acceleration in the sensor/body frame [5].

Communication channel between all electrical components is organized with commonly used Serial Communication techniques UART. Data frames can have different lengths depending on configuration [6].

In order to switch from manual to automatic mode the operator should start the cran by pushing the button on the “pult” and the button on STM32F7 Discovery control panel. Data transmitting algorithms consists of following steps:

- Forming data packages and transmission to the communication channel;
- Changing control mode from manual;

- Forming data packages from STM32F7 Discovery with final coordinates and transmission to the communication channel for processing by PID-controller;
- Receiving data packages from STM32F7 Discovery by PID-controller, processing and transmission to the encoder driver;
- Receiving data by encoder driver and start crane boom motion.

The use of microcontroller STM32F7 Discovery as a core of the main control board gives the possibility to control the encoders, increase the accuracy and motion score and transmit signals between functional blocks at the same time (Fig.3).

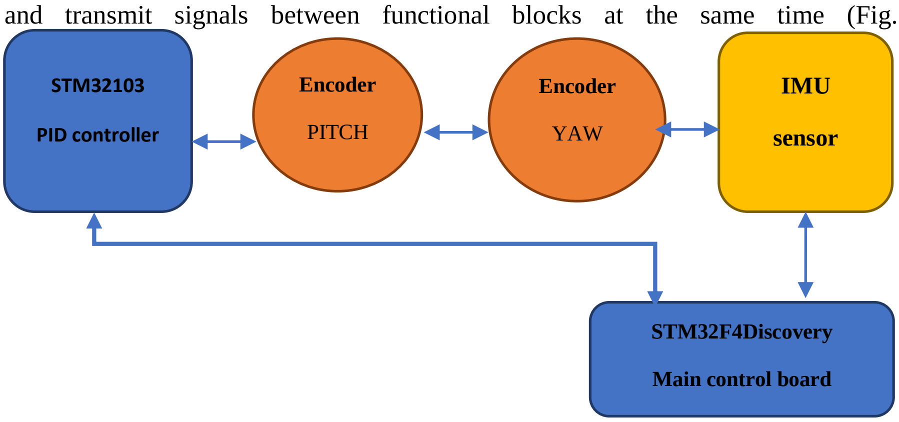

Fig.3. Block diagram of the hardware

3 Processing algorithm

Processing algorithm is based on equation of motion and calculates parameters in real time. To obtain equation of motion there is longitudinal form of motion used. It is the movement with zero roll, when the gravity vector and the velocity vector of the crane camera lie in its plane of symmetry as shown on Fig. 4.

The yaw and pitch properties are returned as Euler angles. The values of the pitch and yaw properties are returned in radians.

The camera crane moves along two axes with lifting back and forth. Accordingly, during lifting, the length of the camera crane (l_0 to l), the angles of pitch(θ-θ_0) and yaw (φ-φ_0) change. To set the right length l_{set} of camera crane equation of motion is used:

$$l_{set} = l_0^2 + l_0^2 \cdot tg^2\left(\left(\theta - \theta_0\right) \cdot \frac{\pi}{180}\right) + l_0^2 \cdot tg^2\left(\left(\varphi - \varphi_0\right) \cdot \frac{\pi}{180}\right). \quad (1)$$

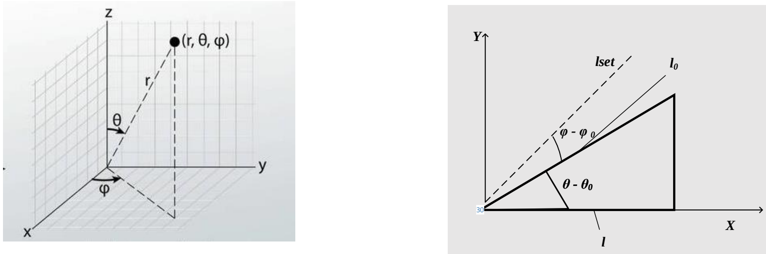

Fig. 4. Graph of motion

The final position coordinates (x,y) are determined through pitch and yaw angle values:

$$x = (\sin(\varphi \cdot \left(\frac{\pi}{180}\right)) + x_0$$
$$y = (\cos(\varphi \cdot \left(\frac{\pi}{180}\right)) + y_0 \qquad (2)$$

Processing algorithm is implemented into the main control board (STM32F7 Discovery). It supposes receiving and processing data flow continuously from IMU in real time, computes coordinates of camera crane motion and transmit to the PID controller (STM32103) to correct with the measured coordinates. Finally, it gives the right signal to rotate encoders in set motion direction and camera crane start to move.

The software recognizes its original positional data automatically, within +/- 30 degrees at camera crane and head in both tilt and pan dimensions. Processing algorithm computes the coordinates of final position and output on LCD display or console as shown on Fig.5.

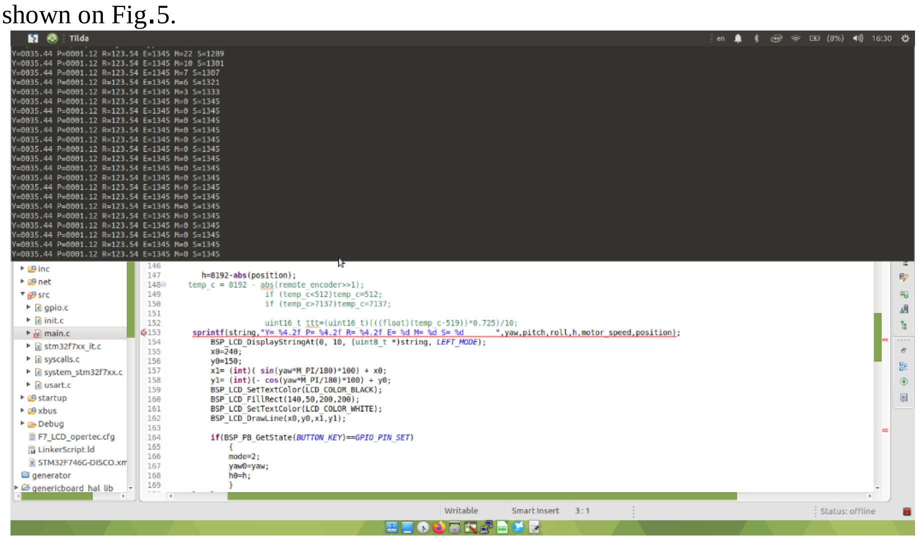

Fig.5. Screenshot of processing algorithm of motion control system

An analysis of the compatibility and consistency of manual and automatic control modes designed a block diagram of the algorithm as shown on Fig.6.

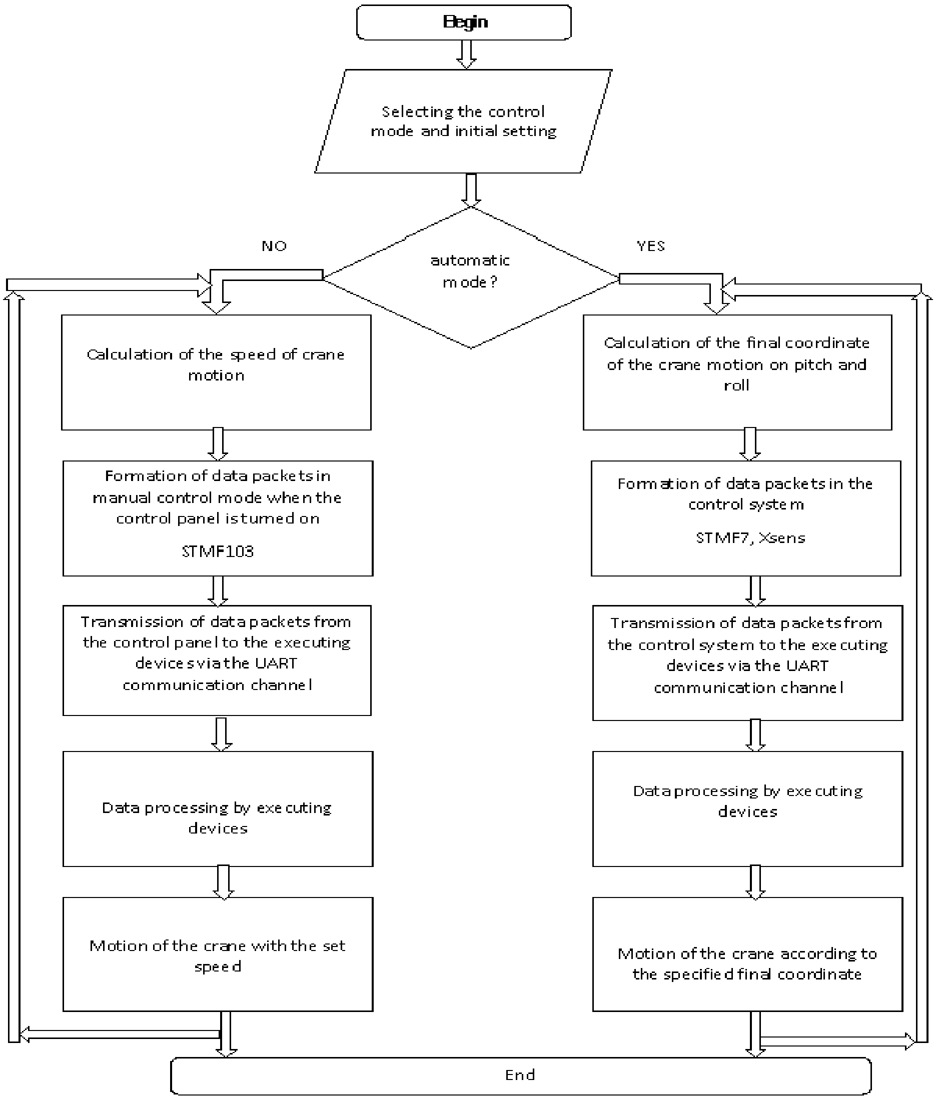

Fig.6. Compatibility and consistency manual and automatic control modes

4 Test

As described above, to increase the accuracy of the system and correct the operation of encoders Inertial Measurement Unit (IMU) applied. selected the Xsens MTi 10-series with AHRS, VRU, and IMU, the integrator three different integration levels. The module is based on an industry-proven, cost-effective MEMS-based orientation sensor, and has an integrated, full-featured sensor fusion algorithm with easy to use SDK as shown on Fig.8.

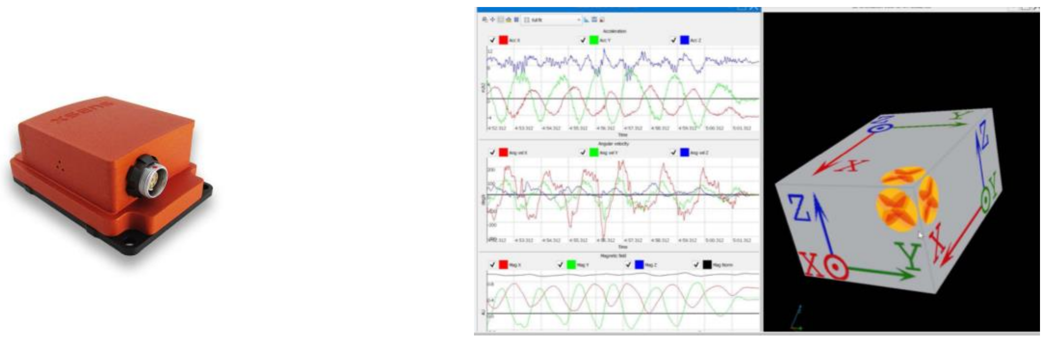

Fig.8. Inertial Measurement Unit (IMU)

Main board sensed the signal from an IMU sensor thereby feed backing it into the PID controller which transfers data through θ and φ for monitoring both rotations of encoders.

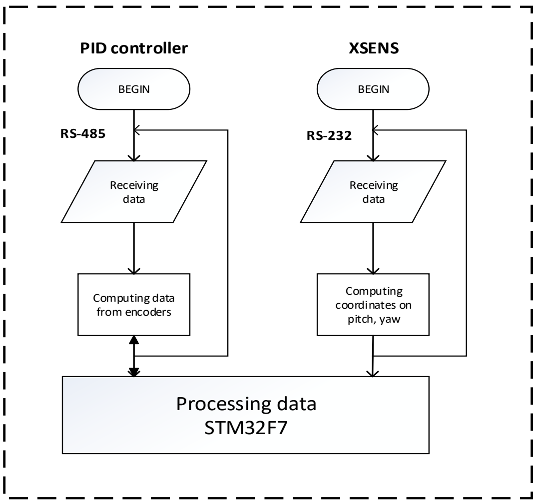

Fig.9. Processing data by PID and IMU

PID controller calculates an 'error' value as the difference between a measured length and a desired set point (*lset*). The controller attempts to minimize the error by adjusting. When encoders start to rotate motors at the same time the estimation of rotation angles will be used as feedback to the PID controller and IMU to estimate and correct the position of camera crane.

To verify the operability of the developed system, it was tested and experimental data obtained as shown on Fig. 10.

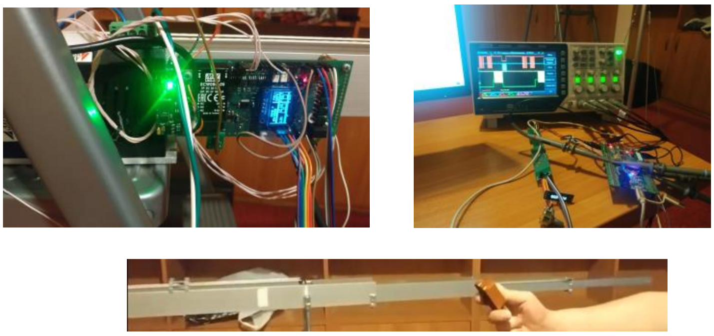

Fig.10. Experimental tests

The results of experimental tests confirmed the correct functioning of the processing algorithm and the operation of the system as a whole, and on their basis we can distinguish the main features of automatic mode:

- tracking precisions – accuracy encoders, IMU and PID controller are tested and function marvellously with tracking UART protocol (RS-232, RS-485) without cumulative error.
- stable data delivery – designed software superb gear processing and reliable STMicrontrollers.
- easy control, compatibility and consistency based on STM electrical crane control system, it works in both manual and automatic modes and can be easily switched.

Conclusions

Developed automatic crane control system has possibility to switch between the manual and automated modes. The system developed provides real-time LCD displaying of crane and camera data content, easy calculation and operation. This automatic control system simplifies the operator work, increases the control score, uses the powerful microprocessors and precision IMU sensor and actuators.

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