Time measurement synchronization using GPS units

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Abstract—This article deals with methods research for synchronization pulses utilization provided by some GPS units for measurement synchronization. Initially there are problems of GPS described. Further there are drawn out realized prototypes of measurement systems based on microcontrollers where is expected milliseconds measurement accuracy followed by description GPS synchronized time source implementation in logic gate arrays (FPGA), which allows accurate measurement of microseconds and better. This article describes the theoretical premises and selected measured properties of realized solutions. In conclusion there are prepared experiments described which should be realized during research of this issue.

Keywords—GPS, synchronisation, measurement.

I. INTRODUCTION

 Nowadays GPS units are widely used commercially especially in combination with mobile devices as PDA with relevant application and map background such a car or outdoor navigation, etc. However many GPS units provides not only information about the current position, there is also a very precise timestamp (with an accuracy of microseconds), which is used as the key function of this work [1].

 Considering the cost of GPS units there is no complicated measuring units realization for GPS services utilization. Moreover, GPS synchronization allows synchronization of large distances units, where a wired solution would be either very costly or impossible. Therefore, the transmission of measured data or remote control-driven GPS units use the wireless communication (wireless serial port radio-transmission tested yet, we prepare Wi-Fi connection version). The realization of this research is focused on principles described above.

 As a disadvantage can be mentioned the possibility of disconnection of the GPS system of American government (primarily GPS has been designed for military applications).

 But there are new navigation systems prepared (Glonass, Galileo) and their implementation into described solution in the case of assumed similarity solutions should not be a greater problem.

 II. GPS OVERVIEW

 GPS (Global Positioning System) was created and realized by the U.S. Department of Defense (DOD) and originally established for military purposes of US army. There was the effort to reduce the large number of navigation aids and to overcome the limitations of previous navigation systems and make it universal, portable and easy accessible. The design of GPS is based partly on similar two ground-based radio navigation systems. In the eighties the GPS was allowed for civilian purposes (in degraded version).

   The current GPS consists of three major segments:
   - Control segment
   - User segment
   - Space segment

   The control segment is composed of set of ground stations for GPS satellites monitoring, control and maintenance.

   The space segment is composed of the orbiting GPS satellites, or Space Vehicles (SV) in GPS parlance. The GPS design originally called for 24 SVs, eight each in three circular orbital planes but this was modified to six planes with four satellites each. Satellites orbits are in defined altitude and radius.

   The user segment is composed of U.S. and allied military users of the secure GPS Precise Positioning Service, and civil, commercial and scientific users of the Standard Positioning Service.

   A. GPS Concepts

   The principle is based on the theory of relativity. To determine the position there is the need two different time intervals, or at least three transmitters, satellites. Next additional satellites refining measurements and provides additional extra information (altitude). Measurement of time differences is not primitive process and there is a set of error sources (GPS receiver clock error, etc.). It is also dependent on a constellation of satellites (for example receiver on one line with satellites). To minimize errors, the system is made up of 24 satellites in six circular orbits. Using the appropriate distribution is the availability of the GPS signal almost ideal.

   Service which provides civil GPS user segment is called SPS (Standard Positioning System). This allows the
positioning and time information receiving. All satellites transmit at the same frequency (L1), for more precision it is possible to use the military and second frequency (L2) for the information improvement. PRN (Pseudo Random Noise) is associated for each signal which determines the satellite source of the signal (ordinal number). The receiver must be able to receive the signals from at least four satellites (nowadays all twelve). The quality and rate of the receiver has a major impact on the entire measuring chain.

On each satellite is a very accurate time source, atomic clocks, which are precisely synchronized. This time is also included in the message which is decoded by receiver. GPS has its limitations. Generally it is mainly the availability of the satellite signal (a problem in buildings and estates which prevent signals receiving from satellites).

B. NMEA Protocol

NMEA 0183 is a combined electrical and data specification for communication between marine electronic devices such as echo sounder, sonars, GPS receivers and many other types of instruments. There exists a new standard NMEA 2000 which was extended with number of sentences used for communication. Each sentence has established structure. Most of the available GPS receivers provide this protocol. This feature is very useful for microcontrollers processing.

III. EXPERIMENTAL WORK WITH MICROCONTROLLERS

To test the processing of data and synchronization from the GPS unit there was created the application with microcontroller, which is not strictly industrial in nature, however we can find an area of possible use of this measuring chain thanks to the obtained results.

Experimental application was a system of few measuring units actually used for sport purposes, specifically for the time measurement of fire attack. We realized three units for tests. First unit is a master (start) unit for measurement control and communication with personal computer where is running data processing. Next two units are measuring slaves (targets). The basic concept is on the picture 1 [3].

A. Start Unit

The start unit is based on sufficient powerful microcontroller NPX P89LPC952 including a number of next functional blocks. Whole unit consists of a microcontroller, which allows to communicate with a supervisor workstation (combination of personal computer and appropriate application), target units and GPS module and control next block as it shown at picture 2.

Microcontroller and all other circuits are powered from a source with “very low drop” stabilizer to satisfy power requirements for the best use of the proposed current source. The start unit is powered by lead-acid accumulators commonly used in automobiles (great capacity). This means several weeks of operation with the average operating current time of entire start unit approximately 60 mA.

As a trigger circuit there is a starter gun used which is connected with a separator to the microcontroller interrupt input. After interrupt signal invoked by gun the current time value is read from the GPS receiver, calculated and stored. For the start unit has been used and tested the GPS module from Leadtec LR9552. The output of the module is designed as RS232 or TTL serial device, in this case we use TTL levels because it brings advantages. Microcontroller does not need any additional support circuits for conversion. For other types there is a possibility to convert RS232 to TTL.

GPS module also has an output that provides a-second pulses with an accuracy of one microsecond. These pulses are connected to the second microcontroller interrupt input and we are able to synchronize internal clock by them.

Given the need for serial communication with more than two units one of the microcontroller serial input has to share more data sources. Standard multiplexer is used for this task. If we need we can switch to communicate with a PC (personal computer) or ASK (Amplitude-shift keying) transceiver that implements wireless serial port. This unit is used to communicate with a remote target units (the distance between start and target unit is about 70 meters in our case), respectively, it sends orders to target units and read the measured data and service conditions of units.
For communication between the microcontroller and remote units, or PC, communication protocols were developed. For bi-directional communication we can use commands such as:

- **RESET** - after receiving the target unit completely reset all settings to the initial state and sends the confirmation
- **STATUS** - after receiving the target unit has to return information about current time stamp or synchronization message. Without confirmation of the synchronization message by all units the system cannot start measurement because it means that it has not completely initialize GPS module or a hardware error has occurred that prevents the perfect function of unit.
- **MEASURED DATA** - data consisting responses from the target units. They are designed for superior system, in this case PC, where they are also inserted into database and analyzed. In this set we can find start time value and break time of targets and the state of power source in each target.

Due battery powered system there are measured voltage values on batteries with integrated A/D converter. We can decode the state of battery and this information is then used in a PC application, which monitors and user is prompted to exchange in case of a fall below the lower limit.

The start unit also enables autonomous operation when the LCD is displays time, which represent the difference between start and break time of appropriate target.

The last part of the start unit is the digital output of the microcontroller to control the alarm, indicating a start of the race (measurement).

**B. Target Unit**

Target unit is based on the same microcontroller NPX P89LPC952 block and its structure is very similar. The main difference is in the firmware implementation.

Target unit is battery powered but due limits of extension there are used NiHM triple A batteries. The main reason was to minimize it to be built into the target stands. Current consumption is at average about 40 mA. It means we can use target units about two days which satisfies requirements for given application.

After power on the target unit try to communicate with GPS module. In the case of correct start-up (cold start consumes about 40 seconds) and met requirements for the number of visible satellites and power over the low limit, the unit responds positive to periodic query of start unit.

The actual time is synchronized by pulses from the GPS unit and appropriate corrections are made. On the second interrupt input is connected an electromagnetic sensor with an electronic converter, which senses the presence of the target. If the message about start of measurement is received, the unit is waiting for a pulse generated from the interruption signal of the sensor. After interruption the time is read by GPS module and corrected by target unit. This information with the state of battery is sent to the start unit. In other cases, the message is sent on failure (the target must be positioned correctly). Correct setting of the target unit is indicated by an LED.

Communication runs over wireless serial module and other tasks are directed by the starting unit. Target unit only reflects the present state of the time, battery power supplies, etc. on demands.

**C. Measurement Application**

The application for easy operation and data processing was developed in Microsoft Visual Studio 2008. Application controls the whole measurement process by starting the unit. The output is formatted ordered table which is exported to MS Excel format. Communication between PC and start unit is realized by simple message on serial port or by virtual port offered by Bluetooth devices.
D. Results by microcontroller experiments

The entire measurement chain has been tested in preparation for competition and at sharp competition only once. Originally developed time measurement application provides time with linear growing delays. GPS based version has not these problems however need to fix time corrections. The problem that arises in this particular case is that we cannot display timing in real-time because the speed of wireless communication is not sufficient to transfer the time and status. Against the old version where the measurement was limited by long metallic wires but there was only one measuring unit and the time could be displayed, this is very uncomfortable limitation. Range of units in the open field is limited by used wireless technology for data transmission. With a small antenna this means about hundreds of meters distance. Wireless technologies for more transparent network (as wi-fi, etc.) bring more complications for used simple microcontrollers.

This method allows the solution with time precision in milliseconds, which is sufficient for developed application.

IV. EXPERIMENTS WITH GATE ARRAYS

For simple measurements of on/off values the methodology described in the previous chapter and validated on the real task is sufficient. GPS provides more accurate pulses and even if it is possible to use more powerful and faster microcontroller, we choose the gate arrays for next steps. This concept is shown in Figure 6.

![Fig. 6 FPGA Implementation](image)

Basic part was implemented in Xilinx Spartan 3 which is connected with connected with A/D circuits and GPS unit. First tests were not successful due bad PCB design (A/D circuits were generated noise with constant voltage on input due thermal conditions near stabilization circuit). NMEA protocol sentences are partly implemented with a source of accurate pulses controlled by synchronization pulses by GPS. In addition calculation of moving average was implemented for more precise time determination. In this time we work on memory scope based on described technologies.

V. CONCLUSION

Use of GPS modules for measurement with need of precise time based is possible and it brings very interesting results.

The implementation of devices based on GPS could not be expensive against wired measuring networks. For next generation of devices there is necessary to find better wireless connection solution for faster data transmission. For microseconds accuracy there is an open range of industrial applications as in the near future designed impact measurement in product pipelines [2].

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REFERENCES