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Safety systems in rover controller

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ABSTRACT

This study's objective was to determine the level of safety measures used in mobile robot prepared for teleoperation tasks in long distances and harsh environment. The vehicle under test was six-wheeled Mars rover equipped with robotic arm, designed to compete in URC (University Rover Challenge). The analysis has been subjected to the following: communication system, performance of onboard computer and emergency stop system. Communication system has been tested for message exchange speed under various data transmission protocols. Link between base station and mobile robot has immediate influence on onboard computer performance. Emergency stop is an indispensable part of hardware and software, it was tested in different state of the robot to ensure it robustness. This study demonstrates that for the teleoperation control, the UDP protocol is suitable for communication while at the same time allows to maintain low usage of a computing power at the on-board computer.

***Keywords*:** safety, rover, controller, communication, mobile robot, remote driving

1. INTRODUCTION

In the face of development of autonomy, there will always be a need for human involvement in mobile robot tele-operation. Especially the tasks such as surveillance, reconnaissance and exploration will require human supervision. It's crucial that the operator interface be as efficient and reliable as possible. Presented system was created for purpose of use in mobile robot competing in URC competition where it must handle harsh environment and conduct several task remotely in radius of 1 km from the base station. Challenge imitates a simulated Mars rover mission, where it has to collect a sample of soil, analyze it on-board and send results to the base. Another objective is to do maintenance of a simulated generator or deliver objects in the field. Competition is located in MDRS (Mars Desert Research Station) in Utah (USA) where the conditions are similar to Mars environment, red soil, sharp rocks and varied difficult terrain. Rover (Fig. 1) is controlled via tele-operation, all the movements are controlled by human operator, driving, manipulator and probe. Mobile robot is communicating with base using 2,4 GHz 2×2 MIMO Wi-Fi connection that allows to maintain connection up to 1km with line of sight. Hardware used for communication is off-the-shelf which ensure proper link between base and rover. Mobile robot on-board computer is a sbRIO embedded computer, it is programmed in graphical language LabVIEW. Base station is equipped with PC/Laptop computer with LabVIEW software as well. Control architecture is presented in Fig. 2. Telemetric data as well as control data are sent via UDP protocol. On-board computer exchange information with drives controllers via CAN bus.

Figure 1. Mobile robot with manipulator

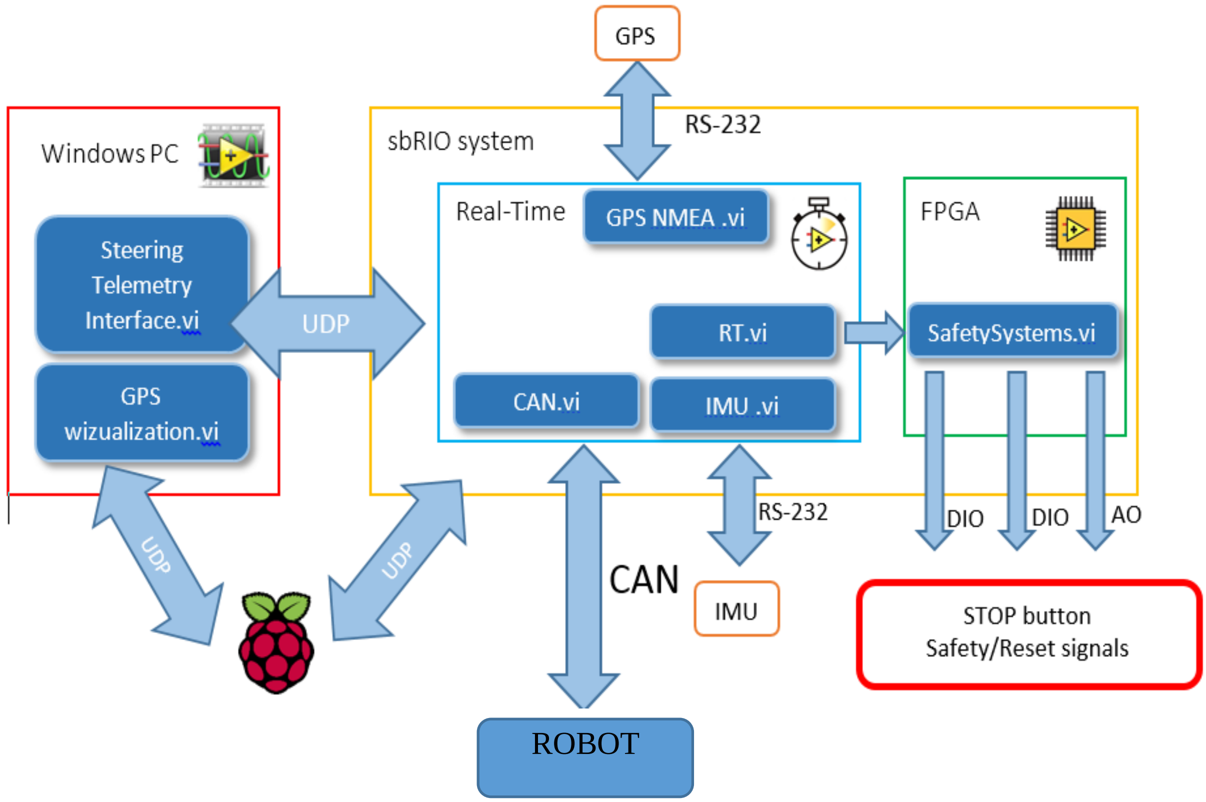

Figure 2. Control architecture

2. MATERIALS AND METHODS

For purpose of this study, system was analyzed indoor. Operator station with base antenna was 10m away from robot. First, different data communication protocols (UDP, TCP/IP, Shared Variable) where tested for delay and rover CPU load. Communication latency was measured as a difference between timestamp of a sent data and time when the same data was received from robot. Data used for research consist of two CAN frames (Identifier U32, Extended bool, Type U8, Payload 8xU8) having 14 bytes in total. Data were continuously sent in 10ms loop from base station. Rover was expecting data in loop without delay but there was a 10ms timeout for data to read. CPU load were directly read from *System Manager* of sbRIO for three different state of robot: a. without connection to the base station, b. with connection to the base station, c. with connection to the base station and data being sent). Each set of data was averaged. The last study included time response of emergency stop button to cut off the power supply from drives and activation of *Safe Mode* in case of connection link lost. This stable control algorithm for anomalous events is commonly referred to as the *safe mode* and consists of control logic that will put the robot invsafe configuration defined by the robots hardware, power and environment capabilities and limitations.[1]

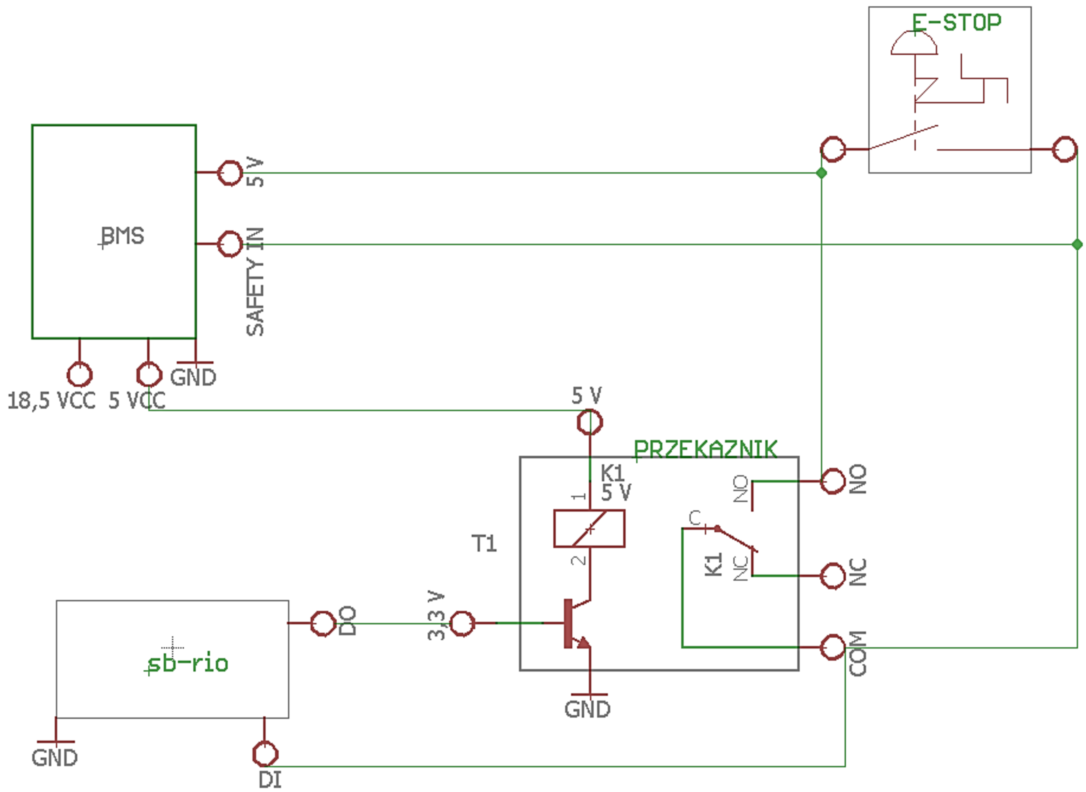

Figure 3. Safety STOP system

3. RESULT

Results for latency are showed in Fig. 4, bar chart visualize average delay time in data communication between the base station and the robot. Average CPU load is presented on chart in Fig. 5. Shared Variable protocol which is a native LabVIEW protocol for data communication had average delay approximately about 450 ms. Other two protocols had similar results around 50 ms, UDP with 43ms and TCP/IP with 70ms . Pushing emergency stop button on robot immediately stops rover drives, as E-STOP signal is directly connected to BMS (Battery Management System) as shown in Fig. 3. Time in which the operator will be informed about E-STOP beeing pressed depends on the latency time in the communication. In this case its about 50 ms when operator is beeing informed about emergency stop activation. This 50 ms results from facts that DIO are read in 20 ms loop see Fig. 4. Similary, when the operator presses the E-STOP button on his panel, drives will stop after aprox. 50 ms. In case of link lost with base, rover instantly stops. To better understand timing and latency of results, timing structure is shown in Fig.4. The base program runs in 10 ms loop to visualize data and another thread runs also 10 ms loop to send and receive data. As well robot has 10 ms loop for sending and receiving data and 20 ms loop for read/write signal from/to E-STOP.

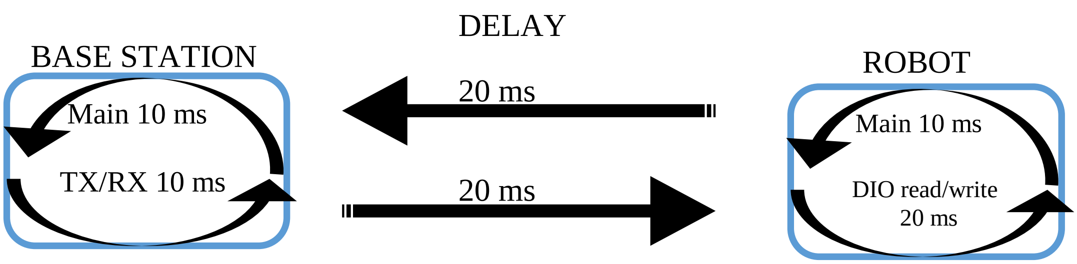

Figure 4. Timing structure of system

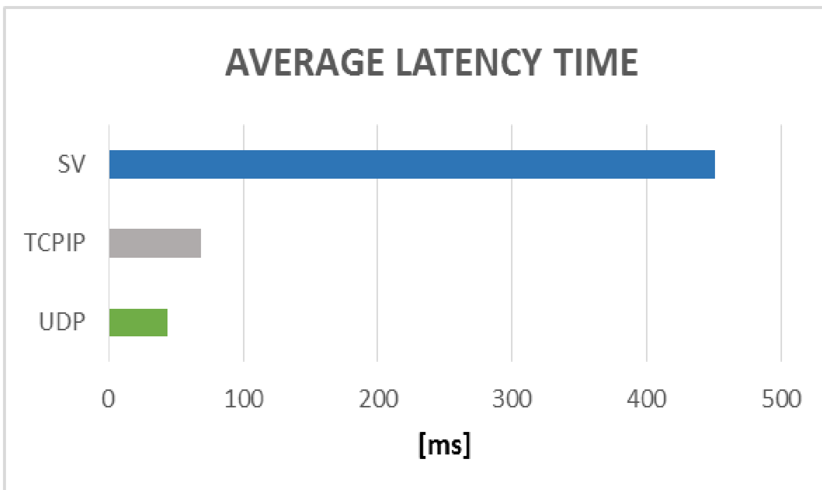

Figure 5. Average delay for differents data protocols.

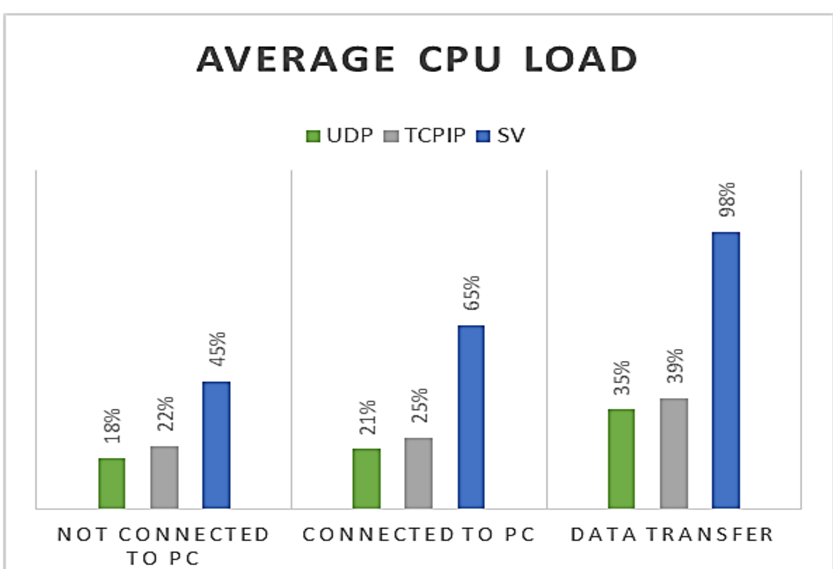

Figure 6. Average CPU load with different data protocols and states of robot

4. TERRAIN TEST

System was tested in the area of MDRS (Mars Desert Research Station) in Utah, during competition URC 2016. The area consisted of various loose and hard surfaces, the terrain was also varied in elevation and slopes. Some of the competition area was out of line of sight for antennas. Which created a threat of loss of connection. Semi-finals were at first day, run was consisted of few obstacles to overcome, base station was few meters away from track, as well as others teams base stations. First problem occurred at the beginning where connection with robot was disturbed by other teams Wi-Fi links. Some of the teams used to much powerful transmitter, which was illegal. After switching off transmitters by some of the teams, our connection was sufficient to control the robot. This run was very close to base station in contrast to the most difficult task which was in radius of 1 km from base station. The goal was to get to the gates (Fig.6) which were scattered around base station in radius of 1 km. One of the gate was out of line of sight which may affect on robot communication link. This was an excellent opportunity to test *safe mode* on robot. However, despite the weak signal, communication was maintain all the time. Nevertheless after this task, we run a simulated test in which we physically disconnected Ethernet cable from antenna, as we predicted *safe mode* turned on and robot stopped. During the competition the system behaved correctly. Unfortunately non data was gathered during competition which could be used to compare to laboratory data. However, evaluating the system performance on the field can be said that latency was higher than 40 ms this was based on camera image from rover. In overall system work well.

Figure 7. Terrain tests in Utah

4. 1. Safety in user interface

Safety systems on-board robot are primary tools against faults occurence. Operator is obliged to be remain vigilant at all times. To help him with that a user friendly-interface must inform about any unexpected behaviour of root system. User inteface used in terrain test is presented in fig. 8 , there are information about , how to control robot or manipulator, actuall status of connection link, status of emergency button as well as emergency stop for operator. Besides basics information about control operator can also see actual data transfer beetwen robot and operator as wel las visualization of speed. This interface has also builted in safety measures for control, for example operator can not set a high step of velocities on drives if robot is not moving, as well as always the last commands sended are zero velocities for drives this ensures that robot will always stop when operator stop sending control commands. This interface was created in LabVIEW, advantage of this software is creation of user interface and at the same time creation of code for this interface.

Figure 8. User interface

5. DISCUSSION

Without a doubt most important parameter in tele-operation mode is the latency. Experiment carried out by Ferrel, presents that delays of 0.3 s for human operator is not enough to maintain sensor-motor coordination during manual teleoperation [2,3]. Achieving a result of approximate 20 ms delay in one direction is enough to operate a robot, even though UDP is a lossless protocol, during research it has not been noticed any significant data loss that would effect on robot behavior.

TCP/IP protocol had higher latency and CPU load than UDP. Shared Variables used most of processing power and has the highest latency reaching 450 ms, which is not acceptable for tele-operation mode. Emergency stop signal indicator for operator is bounded to actual latency. In case of communication link lost Safe Mode is enabled on mobile robot thus it stops immediately. Safe Mode is widely known fault protection techniques especially for space ships [4]

6. CONCLUSIONS

Presented studies pointed out UDP protocol as a sufficient protocol for data communication for tele-operated robot. Other data protocols reduce efficiency of the on-board computer. Emergency stop system is based on hardware, even without communication with base system will work in case of an emergency. The Safe Mode resets velocities for all drives to zero whenever link is lost, this guarantee robot to wait in place for reconnection with the base. As for future plans the Safe Mode will be more autonomous mode and whenever link is lost and even after long time connection is not regained robot will autonomously drive back towards the base station. Future studies will lead to development of on-board System Fault Protection Engine [5] that can autonomously handle not only communication faults but also battery management or data processed on-board rover. As [6] proposed for a human expedition to Mars, a case can be made that the best strategy for initial exploration is not to actually land the humans on Mars, but to put the humans into Mars orbit and operate on the surface by the technology of teleoperation. This will provide the results of human exploration, but at greatly reduced risk and cost.

Biography

Kacper Andrzejczak: a PhD student on the Faculty of Electrical, Electronic, Computer and Control Engineering of Lodz University of Technology, one of a head programmer in team Raptor. LabVIEW Student Ambassador at Lodz University of Technology.

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