Development of Mobile Research Robot

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Abstract: For new autonomous mobile robot design, the real time problem analysis at different periods of robot activity phases is made. The robot sensor and actuator cluster structure is used. At first the robot is determined as a hard real time system when all phases defined and executed sequentially are in hard deadlines. At second for the robot activity with hard and soft deadline execution phases is proposed using of the time/utility function (TUF). For time and energy consumption estimation, the flexible robot physical model is developed and used. Wireless technology is proposed for new autonomous mobile robot design.

1 INTRODUCTION

New mobile research robot development for education and training purpose is urgent, despite now there are different ready-made research robots (Adept mobilerobots, 2011a; b), (Segway Robotics, 2012) which were purchased primarily by researchers. Before new commercial research of autonomous robot for hard and unstructured environment design began, there were different significant problems necessary to solve: position estimation, obstacle avoidance, motion trajectory planning and map building, timely and energy consumption estimation (Choset et al., 2005).

Historically the term “autonomous mobile unmanned robot” implies a real time system (RTS). Often systems are estimated and classified as hard, firm or soft RTS. The required deadline is the decisive subdivide factor. But it is the determined parameter of application and environment. When the deadline failure threatens human life, the hard design system is obligatory. In other kinds of applications the permissible complete task execution time (ET) can be firm but at the same activity (phase) the RTS can be soft. The hard system can be considered as a special case of soft RTS.

Generalized timeliness calculation meter time/utility function (TUF) was proposed by Jensen in 1976. TUF is a generalization of the deadline constraint, specifying the utility to the system resulting from the completion of an activity as a function of its completion time (Ravindran et al., 2005). When activity time constraints are expressed with TUFs, the scheduling optimality criteria are based on accrued activity utility - e.g., maximizing the sum of the activities’ attained utilities, assuring satisfaction of lower bounds on activities’ maximal utilities. Such criteria are called Utility Accrual (UA) criteria. It can be especially useful for outdoor robot control in environment with dynamically uncertain properties (Balli et al., 2007). An energy-efficient, utility accrual, realtime scheduling algorithm called the Resource-constrained Accrual Algorithm proposed by Wu, Ravindran and Jensen (2007). Other optimization algorithm called Profit and penalty aware scheduling algorithm proposed by Li et al. (2012).

2 TIMELINESS ESTIMATION OF AUTONOMOUS MOBILE UNMANNED ROBOT

Autonomous mobile unmanned robots’ general structure includes: one central unit CU (main processor), clusters of sensors Sn and actuators Ac with interface nodes. All nodes and information lines can be characterized with some real time properties (time delay, throughput, security).

Activity execution phases for an unmanned outdoor Robot is represented by N+1 main finite automata states and different kinds of execution time intervals T_0, T_1,… T_k, …T_N. Phases k can include particular phases or a number of N_k states and execution cycles or activities t_{kw}. Execution cycles

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can be performed concurrently or sequentially. Information from different sensors can be obtained simultaneously. Concurrency of mechanical actuator and electronic operation execution is especially important for optimal real time robot design.

At *phase zero* (time interval T_0) the registers of nods are charged with data from the main program. This program can be hold in ROM of central unit or loaded using wireless connection from user data base. This zero phase is not necessary to enclose in the autonomous mobile outdoor robot real time characteristic estimation.

Phase one (time interval T_1) – the environment estimation and building the route map:

- T_{11} the robot start point estimation using GPS (t_{1gp}), data acquisition by video camera module at start position (t_{1vi}, data acquisition from digital compass (t_{1cm}) and data acquisition from infrared optical short range distance meter (t_{1sd}) and infrared optical long range distance meter (t_{1ld}), start point coordinate estimation (t_{1cu}) using CU.

Data acquisition from GPS, digital compass and distance sensors can be executed simultaneously in time t_{1vi} required to complete data acquisition by video camera module. Then start point coordinate estimation in time T_{11} is t_{1vi} and t_{1cu} determined

- T_{12} is a sum of times required to turn camera in horizontal (t_{1th}) and vertical (t_{1tv}) directions to search for the first nearest object, using servomotors and image acquisition time getting information about recognized objects $t_{1vi.}$ This process repeats as much times N_{1tm} as needed to investigate view sector for the object. T_{12} is N_{1tm} ,t_{1th} , t_{1tv} and t_{1vi} determined.

At the optimal conditions $N_{1tm}=1$

- T_1 route map calculation (t_{1cum}) by central unit using main algorithm and data from GPS, digital compass, video camera module and distance sensors.

$$T_1 = T_{11} + T_{12} + t_{1cum} \qquad (1)$$

Phase two (time interval T_2) - robot turning to the required direction actuating both left (t_{2trl}) and right (t_{2trr}) motors. Motors are actuated simultaneously, it can be accepted that their operation time is equal $T_2 = t_{2trl} = t_{2trr}$

Phase three (time interval T_3) – robot movement by calculated route map to the first, second, or N_{st} objects, actuating motor drivers, distance encoders, video camera module and compass:

- image acquisition by video camera module (t_{3vi})
- driving and steering (t_{3ds}) to the object reading data from distance *l* encoders and required direction α from compass. T_3 is N_{st} ,t_{3ds} , t_{3vi} determined.

Phase four (time interval T_4) –investigation of object parameters using video camera module (t_{4vi}) and central unit program (t_{4cuo}). T_4 is t_{4vi} and t_{4cuo} determined.

Phase five (time interval T_5) – obstacle avoidance: obstacle determination using video camera (t_{5vi}), avoidance decision taking by CU (t_{5cuob}) (jump over or go around), obstacle avoidance realization (t_{5rob}). T_5 is t_{5vi} , $t_{5cuob,}$ t_{5rob} determined.

For the robot real time characteristics' investigation, it is suitable to select some application specific limited route map and time interval T^1 for the calculation and select it as the *deadline*.

A deadline can be determined for each execution phase. When sequence of all of the phases can be determined in $WCET_i$ (worst-case execution time) - the robot can be determined as hard RTS.

$$T^1 = T_1 + T_2 + T_4 + T_5 = \sum_i^5 WCET_i = D_h \qquad (2)$$

To compare and estimate different robot realization structures using (1) it is necessary to select the same numbers of N_{1tm} and N_{st}.

For sophisticated autonomous mobile robot timelines with task completion slack time, start time and soft deadlines utility accrual UA approach can be used. The *Utility* (U) depends on the activity's completion time for phases T_i and particular cycles t_k. These soft time constraints are subject to optimality criteria such as completing all time-constrained activities as close as possible to their optimal completion time — so as to yield maximal collective utility. Time/utility functions is a generalization of the deadline constraint, specifies the utility to the system resulting from the completion of activity as a function of its completion time.

Activity *ji* utility (*U*) calculation is useful to compare the realization time t_{ji} and some soft deadline d_s (Figure 1.).

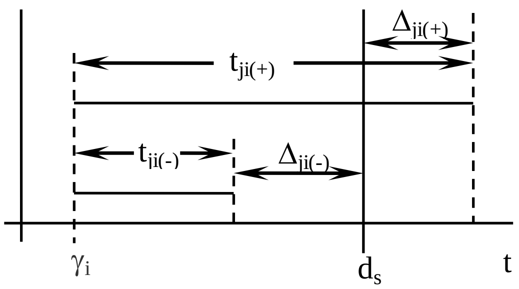

Figure 1: Activity j realization with deadline $d_{s.}$

This soft deadline depends on environment where is acting the autonomous mobile robot. While developing our research robot physical model the d_s usually was equal to image processing delay (Baums et al., 2011).

Performing any tasks there is some probability $p_{11(+)}$ of missing the deadline d_s. For the activity *ji* utility calculation, this time ($t_{ji(+)}=d_s+\Delta_{ji(+)}$ is $\gamma_{ij}\tau_{ij(+)}d_{sij)}$ designated, γ_{ij} - task starting time point.

For the first activity t_{112} (*phase one*) camera turns simultaneously in horizontal and vertical directions ($t_{1th}\approx t_{1tv}$):

$$U_{112} = \Im_{112} = \gamma_{12}\tau_{1ht(-)}d_{s12} - p_{12(+)}\gamma_{12}\tau_{1ht(+)}d_{s12} \tag{3}$$

The *utility accrual* UA of T_{11}):

$$UA_{11} = \Im_{112}+\Im_{1\,vi} + \Im_{1cu} == \Im_{112}+\gamma_{1vi}\tau_{vi(-)}d_{s1vi}- \\ -p_{1vi(+)}\gamma_{1lvi}\tau_{1vi(+)}d_{s1vi}+\gamma_{cu}\tau_{cu}\, d_{scu} \tag{4}$$

The *utility accrual* of T_{12}:

$$UA_{12} = \Im_{12} = N_{1tm}\,(\Im_{112}+\Im_{1vi}) \tag{5}$$

$$TUF\ UA_1 = U_{112} + UA_{12} + \gamma_{cu}\tau_{cu}\, d_{scu} = \\ = \Im_{112} + \Im_{12}+\gamma_{cu}\tau_{cu}\, d_{scu} = \gamma_1\, \Im_1\, d_{s1} \tag{6}$$

To compare this Time/utility function model with the hard RTS model, it is necessary to estimate the *utility accrual* for the same 5 phases (2).

$$TUF\ UA = \Im^1 = \gamma_1\, \Im_1\, d_{s1} + \gamma_2\, \Im_2\, d_{s2} + \\ +\gamma_4\Im_4 d_{s4} + \gamma_5\, \Im_5\, d_{s5} = D_s \le D_h; \tag{7}$$

The realization time τ_{ji}, starting point γ_{ji} and soft end point d_{sji} estimation can be made by using some mathematical or physical models (Baums et al., 2011).

For system energy and cost minimization, decreasing of the node number is efficient. For example, one node can be used to transfer data for more than one different sensors or actuators.

3 DESIGN AND INVESTIGATION OF AUTONOMOUS MOBILE ROBOT

3.1 Robot's Physical Model

Flexible physical model for autonomous robot time and energy consumption investigation is developed and published by the authors (Baums et al., 2011). Aerial view of physical model it is proposed on Figure. 2. There is only one node (system node) for actuator (ac - motors) and video camera (se - vision) connection. Other sensors (se - Compass CMPS03, optical range meter Sharp GP2D15 and GP2Y0A710YK) are directly connected to the central unit.

The autonomous robot trip in real environment with different objects was investigated and ant-colony algorithm was used to build shortest round trip route (Baums et al., 2011). Robot's physical model mainly is used for research and student education.

Figure 2: Mobile robot's physical model aerial view.

Physical model's peak energy consumption was experimentally estimated. The following results were obtained: Control board (5V ·50ma=0.250W); 2 SHARP range meters (2·5V·50ma=0.500W); compass *CMPS09* (5V·25ma=0.250W); camera *CmuCam3* (10V·450ma=4.5W); 2 servo motors (2·5V·750ma=7.5W); motor driver (5V·50ma= 0.250W), 2 motors (2·10V·3.50a=70W); maximal energy consumption: $\sum_{ei} \sim 83W$.

3.2 Autonomous Mobile Robot's Design using Wireless Technology

As a central unit for the new generation autonomous mobile robot design was used PDA HTC Flyer. The structure of the robot is proposed on Figure 3.

Main differences between first and second mobile robot physical models are:

- Video camera module. First robot used CmuCam 3 built by Carnegie Mellon Univercity. It had some disadvantages – such as low image resolution, low data transfer rate, camera matrix low sensitivity to the red color. New robot uses built in High-Quality 8Mpix camera module. Because Camera module and system processor are placed on one module – HTC Flyer, image data transfer and processing speed increased greatly.

- Navigation system. For the navigation purposes first robot used electronic compass CMPS09, encoder system, and range finders. New system uses Sparkfun 9DOF AHRS module instead of CMPS09. It includes 3 axis magnetic compass, 3 axis gyro, 3 axis accelerometer and ATmega328 for data processing and transfer purposes. Using adaptive filter (Kalman filter) AHRS module helps to make much more precise robot position and direction

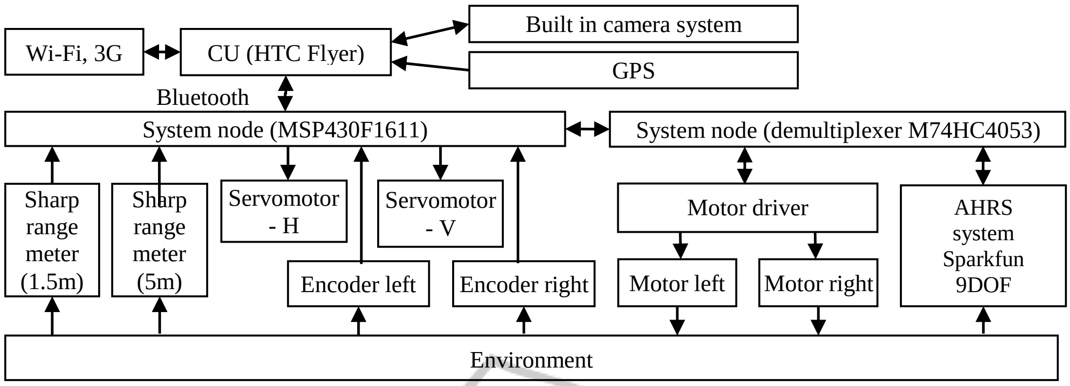

Figure 3: Autonomous mobile robot built using wireless technology.

determination then just an electronic compass.

- CU. Main control unit of the first robot was ATmega32. As a control unit for a new robot HTC Flyer was chosen because of its powerful processor. It is capable to perform calculations quickly.

- Communication abilities. The robot is capable of communication using 3G or Wi-Fi networks. It helps an operator to control robot and get telemetry data from any place in the world where there are available connection to the Internet.

Such a solution for the mobile robot is very flexible giving ability to scale it for a task.

One of the first test tasks planned to realize on built physical model is to detect colored markers in the preset environment, estimate their position, build shortest round trip route and move through it.

4 CONCLUSIONS

For the new autonomous mobile research robot design, the real time problems are significant and it is necessary to solve it in estimated time. For timely analysis, an autonomous robot's structure is based on a single main processor, clusters of sensors and actuators with its interface nodes. In different robot's activity phases the *time/utility* function TUF and utility accrual UA criteria are selected.

For time and energy consumption experimental estimation robot's physical model is used. This model is advisable for student education.

The new autonomous mobile robot is designed using proposed wireless technology.

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