30th Congress of the International Council
of the Aeronautical Sciences
DCC, Daejeon, Korea ; September 25-30, 2016

SENSOR CONCEPT FOR HIGHLY-AUTOMATED AIRPORT TUGS FOR REDUCED EMISSON TAXI OPERATIONS

Sebastian Frank, Per Martin Schachtebeck, Peter Hecker
Technische Universität Braunschweig, Institute of Flight Guidance,
Hermann-Blenk-Str. 27, 38108 Braunschweig
Keywords: **taxi operations, eco-efficiency, TaxiBot, SMAN, 4D operations**

Abstract

The Project Zero Emission Taxi Operations (ZETO) conducts an applied study on combining engine-out, trajectory-based surface operations with new technologies such as automated TaxiBots. The integration of automated tug technologies in order to improve airport capacity and reduction of aircraft emissions will be investigated.

This paper provides an overview of a part of the ZETO project that covers the ground section of autonomous TaxiBot operations on an airport. To enable safe operations, a need for a sensor concept arises, which includes the coupling and decoupling processes.

Following a system analysis to define the requirements and capabilities of the sensor concept, this will be evaluated in a Simulink simulation. The modelling of this simulation and characteristic values are defined.

1 Introduction

With the increase in air traffic forecast in various studies [1], [2] an enormous amount of planning is necessary to guarantee seamless operations. For the inflight phase, 4D-operations are one of the cornerstones of the SESAR agenda [5].

Using current technologies, the growth of air traffic will lead to an increase in the emission of CO_2 and other combustion end-products. However, with the goals described by ACARE [4] and the vision *Flightpath 2050* [3], a significant reduction of emissions is envisioned, which can be achieved by a joint utilization of multiple technologies and operations.

To reduce the emissions during ground operations, the concept of taxiing with a limited number of engines is widely deployed. An even larger reduction can be obtained by using alternate means of taxiing without engine-power e.g. by the application of electrical engines to the landing gear which are powered by the Auxiliary Power Unit (APU). However, these engines weigh more than 100 kg [8] and will reduce the payload and, thus, will cut the profit of the airline.

Another method of engineless taxiing is the utilization of an airport tug to tow the aircraft towards the runway. This approach is currently tested at the airport of Frankfurt/Main in Germany. A special kind of barless tug by the Israeli company IAD, called “TaxiBot” (see Fig. 1), enables the pilot of the aircraft to steer the combination of TaxiBot and aircraft towards the runway, whereas the driver of the TaxiBot drives the tug to the next assignment.

Fig. 1: TaxiBot towing a wide-body aircraft [7]

The current version of the TaxiBot is powered by a diesel-electric engine and aboard the aircraft the APU is used to provide electricity and power for the hydraulic systems, especially the brakes. The advantage of using the TaxiBot is that no modifications have to be made to the aircraft. In order to produce even less emissions, an electric version of the tug is envisaged for the future.

The expansion of 4D-operations towards taxiing would be possible with the addition of automatically driven TaxiBots which are coordinated by special software called Surface Manager (SMAN).

The TU Darmstadt and the TU Braunschweig are currently conducting a joint study named ZETO (Zero-Emission Taxi Operations) that investigates how automatic TaxiBots can be integrated into the taxi operations at Frankfurt airport.

In order to achieve this, the ground processes at the Frankfurt airport have been analyzed, requirements have been gained by interviewing end users at the airport like ground handlers, apron controllers, employees of the German air navigation service provider (ANSP) and multiple scenarios covering various states of operations have been defined. Currently, the tugs feature a diesel-electric engine future versions, however, are likely to be purely electrical, hence the title ZETO.

Based on the analysis and requirements, the TU Darmstadt focused on the development of a HMI for the aircraft's pilot, whereas the TU Braunschweig's main activities were in the conceptual development of automated TaxiBots to define the sensors necessary for driverless driving.

The study is mainly funded by the Federal Ministry for Economic Affairs and Energy of the Federal Republic of Germany. 10 % of the funding is covered by the company Jeppesen, which in turn gains privileged access to the results of ZETO.

The project has been granted the funding as part of the *Luftfahrtforschungsprogramm LuFo V* (5th Research Programme for Aeronautics) and has been started in spring 2014 with a duration of 39 months.

An additional paper produced in the frame of the ZETO project with a focus on the scenarios and the human-machine-interface (HMI) for the aircraft's pilot has been written by Bernatzky et al. [6] and will be presented on the ICAS 2016 as well.

2 Scenario for automatic tugs

The automatic TaxiBots are envisaged for the year 2030. The scenarios described in [6] utilize them to perform only during the taxi-out operations, because the taxi-in phase usually does not take as long as the taxi-out phase and the necessary stop to connect the TaxiBot and the aircraft would delay the arrival at the gate getting the passengers to become more anxious.

In the scenario of semi-autonomous operations, the control of the tug/aircraft combination is given to the aircraft pilot who steers the combination by using the tiller and application of the aircraft's brakes. The tug's operations in order to move an aircraft to the runway are the following:

1. Drive automatically to the departure stand.
2. Connect automatically to the aircraft.
3. Push-back controlled by the pilot with the aid of a walk-out assistant
4. Pilot-controlled taxi to the start-up area near the runway.
5. Automatic decoupling at a dedicated area near the runway.
6. Drive automatically to next assignment.

The most sophisticated scenario of the autonomous operations requires a datalink connection between the tug and the aircraft due to the fact that the tug will taxi autonomously while towing the aircraft. Because the nose wheel is not designed to absorb large external forces, any braking will still be applied via the main landing gear of the aircraft. Thus, a data connection between the tug and the aircraft will be necessary and with that, modifications will have to be made to the aircraft. In this case, the tug's steps are:

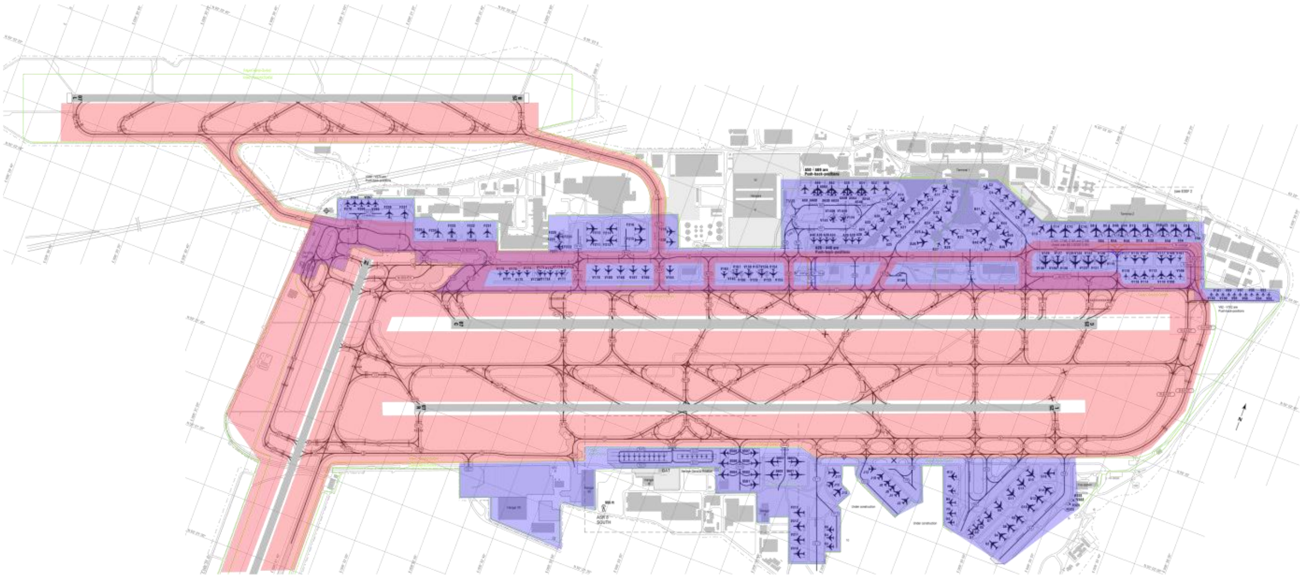

Fig. 2: Map of the Terminal Maneuvring Area of Frankfurt Airport

1. Drive automatically to the departure stand.
2. Connect automatically to the aircraft.
3. Push-back controlled by the TaxiBot.
4. TaxiBot-controlled taxi to the start-up area near the runway.
5. Automatic decoupling at a dedicated area near the runway.
6. Drive automatically to next assignment.

The implementation of a fully autonomous TaxiBot system will largely promote the achievement of the following objectives:

- Expansion and utilization of the available capacity,
- optimization of operations,
- reduction of operating costs,
- optimizing punctuality and compliance with the global planned trajectories,
- reduction of emissions,
- reducing the workload of pilots and controllers.

3 Concept of sensors

In order to enable safe operations using an automated TaxiBot, the vehicle has to feature sensors to sense obstacles, other vehicles, airplanes and persons. These requirements are elaborated in more detail in this section.

The demands on the sensor concept are derived from the requirements for autonomous vehicles. However, the basic requirement is compliance with a trajectory under the given environmental conditions.

3.1 Requirements and analysis

The system has to ensure that any object can be detected. In order to achieve this goal even in case of a single system failure, multiple sensors have to be used. Beside the redundancy aspect of the multi-sensor approach, multiple sensors enable all-weather operability by sensing in various frequency bands or using different principles. Furthermore, the automatic TaxiBot shall be able to drive a given trajectory with an accuracy of ±2m. This strict requirement is necessary to ensure that the aircraft in tow will not leave the taxiway with its main gear or hit any obstacle with its wingtips.

To communicate with a control unit, a data link of some sort is required as well. This communication enables the issuing of tasks to the TaxiBot on the one hand and the transmission of its position and status towards the control unit on the other.

The system requirements for an autonomous operation of TaxiBot are listed below:

- high-precision localization for automatic trajectory tracking,

- detection of the nose wheel of the aircraft to enable the automatic coupling process,
- identification of signs and markings on the airport site,
- detection of moving and stationary obstacles,
- robust against bad weather conditions (e.g. enhanced vision),
- single fault tolerance,
- self-diagnosis of the TaxiBot's systems.

The minimum range for the sensors of the TaxiBot concept derives primarily from the aircraft-tug convoy mass and the towing speed. Furthermore, a minimum distance to the taxiing traffic in front must be respected. This depends on the type of the preceding traffic. Conventional taxiing traffic needs a larger safety distance than a TaxiBot convoy due to the additional jet blast margin.

For a Long Range convoy consisting of an Airbus A380 and the corresponding TaxiBot at an output speed of 12 m/s, the minimum braking distance results in about 8.5 m.

At bad weather conditions or on contaminated surfaces the stopping distance is extended due to lower coefficients of friction. Furthermore, because the pilot flying has to set the aircrafts brakes to stop the convoy and to avoid overload at the nose wheel, the reaction time of a human being has to be added. In addition to the mental reaction time of the human, motor conversion time and response times of the mechanics have to be considered during braking, resulting in a total of about one second.

The sensor concept is to be designed that a safe operation of the TaxiBot is ensured under the event of single failure. The calculated minimum braking distance with a safety margin of 1.4 results in a sensor range of at least 29 meters.

With regard to an enhancement of the cockpit crew's situational awareness and passenger comfort, a significantly larger sensor range is necessary.

3.2 Technology

The TaxiBot was developed by the Israel Aerospace Industries Ltd. (IAI) in international cooperation with the TLD Group. It is tested by Lufthansa Leos at the international airfield Frankfurt in Germany. The Narrow Body (NB) - version is designed for single aisle types of aircraft like the Airbus A320 or Boeing 737 family. For types such as the Airbus A380 and Boeing 747 a wide body tug is already designed but not in operational use yet. Both models differ mainly in terms of their performance and as a result in their size, weight and in the number of axles and tires. Fig. 3 shows the wide body version of the TaxiBot.

Fig. 3: Wide-Body TaxiBot [9]

The TaxiBot is equipped with in-line Steering concept. It means that the TaxiBot and the towed aircraft are always aligned parallel to one another and is directed only through the rotation of all the wheels of the TaxiBots.

The steering concept increases the maneuverability and the possible towing speed which enables the TaxiBot to operate within the time requirements of modern airports.

3.3 Sensor Concept

To achieve this and the requirements set before, multiple sensors will be used. Fig. 4 shows an overview of the proposed sensors. Two stereo Multipurpose Cameras (SMPC) facing fore- and backwards provide the primary information about the environment in real time to the on-board computer. The cameras feature an aperture angle of 45 degrees. These sensors are able to generate spatial figures in the range of about 50 m and two-dimensional images up to 500 m. A stereo matching algorithm is used to find correspondences between the extracted feature-points between the left and right images

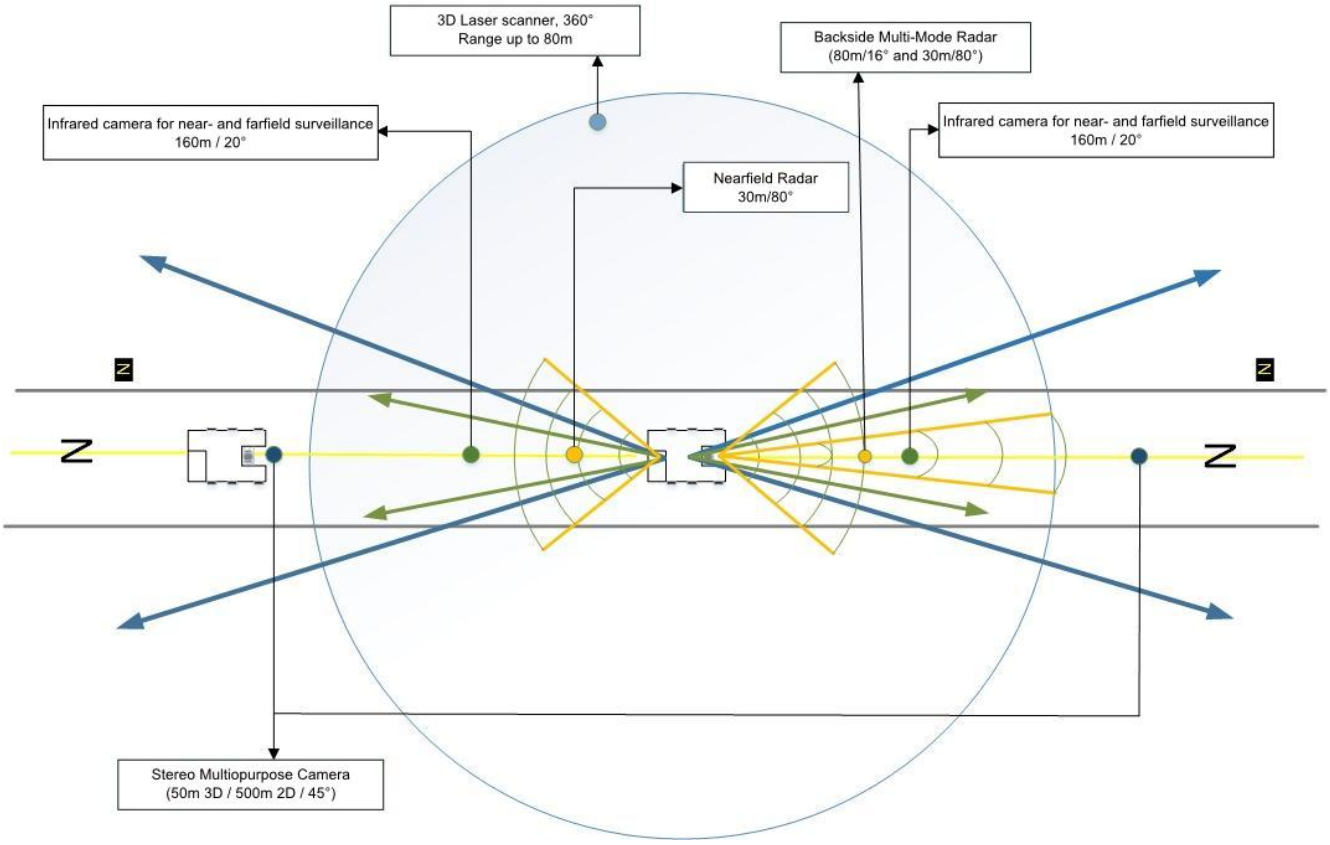

Fig. 4: Overview of the proposed sensors

which provides relative position and orientation between stereo cameras [12].

SMPCs are applicable to recognize markings and signs of the airfield as well as other ground vehicles in good visibility at daytime. Using the Markov random field models, stereo cameras provide a detection of moving objects from mobile platforms [13].

The infrared cameras complement the concept and provide environmental data under adverse weather conditions, such as darkness, rain, fog or snow. Furthermore, objects can be detected if they produce a heat signature.

The 3D laser scanner allows recognition of obstacles, other ground traffic and the runway condition. Due to its high accuracy, it is mainly responsible for the safety distance, setting it to about 80 meters. The sensor is specifically adapted to accomplish traffic situations, such as the safe crossing of other taxiways according to programmed rules. Furthermore, the data of the laser scanner are used to support the stereo camera data during the docking process.

The disadvantage of the radar sensors is a difficult detection of small objects at large distances. However, since mainly metallic and large objects occur on the taxiways, it is assumed that they can be identified using an applicable update rate. Its characteristic range varies between 35 to 80 meters.

The benefit of this approach for sensor set-up is the high increase of collected environmental data which can be optimized to enhance the limits of the human senses. This provides automatic taxi operation as well as enhanced vision in pilot control mode of the *TaxiBot*. For this reason, several independent sensors are used whose coverage is at least equal to the required safety distance of the tug which is approximately 35 meters at maximum speed and good surface conditions. It ensures that objects are detected within the critical area by three different sensors.

In addition to environmental sensors, a fully automated TaxiBot must have a monitoring system to check the technical status of its own sensors. This includes also the monitoring of the vehicle status e.g. the charge of the batteries or the fuel quantity as well as the status of the brakes. Beside of error detection there is a need for an approach to error handling.

The positioning of the TaxiBot is primarily based on GNSS signals. Due to complex terminal architecture resulting in signal blockage or multipath effects, there is a need to combine and validate the GNSS positioning solution with other sources (e.g. map matching). In addition to the GNSS signal and the image recognition, odometry is used to register movements along the track and around the vertical axis to support the positioning. Furthermore, the A-SMGCS system of Frankfurt airport features a position determination using multilateration of a Mode-S transmitter. These data are available and serve further as validation of the TaxiBot own positioning. By using a GPS navigation system with an inertial unit, the provided accuracy is better than one meter [10].

4 Modelling

To determine up to which range level the sensors provide reliable data and whether such conditions influence the defined operating limits, several simulations will be carried out. In the simulations each type of sensor will be modulated according to its characteristics.

The following chapter describes the modelling of the TaxiBot convoy and the characteristic data.

The TaxiBot lifts the nose wheel of the aircraft on a gimbaled platform. The nose wheel is deflected by steering inputs of the pilot. Sensors on the platform of the tug transfer the steering angle of the nose wheel into a steering signal for the TaxiBot. A realistic steering behavior is to be realized by the TaxiBot since each of its axes can be controlled individually.

The modeling of the towing vehicle has been kept as simple as possible. For this purpose the following assumptions are made:

- There are no lateral dynamics in the towed convoy. This allows the use of a single lane model.
- The TaxiBot reacts equivalently to the nose wheel of the aircraft.
- The movement of the nose wheel on the tug is null.
- The TaxiBot will serve as a point mass at the aircrafts nose wheel.

In the derivation of a single-track vehicle system the complex is reduced through many simplifications to only a few equations.

4.1 Theoretic model

The vehicle will be summarized as a middle lane, so that the axes are each considered a separate unit. These simplifications are justified if the conditions set out in Fig. 5 have been met, with *s* denoting the gauge.

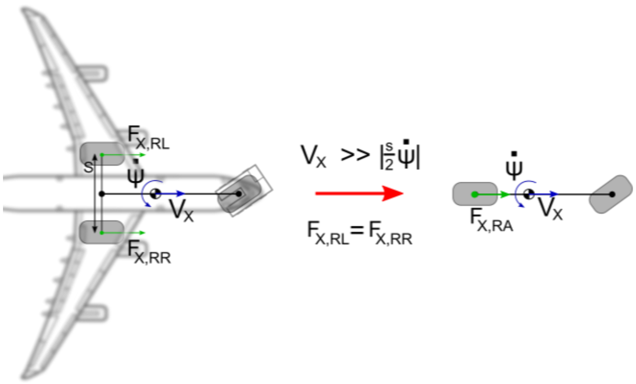

Fig. 5: Conditions in the single-track model

Following the upper assumption in Fig. 5, above a minimum speed of the entire convoy, the longitudinal movement of the individual main landing gear’s wheels yaw motion can be disregarded. The lower assumption presupposes that no transverse distribution of the driving force to adjust the longitudinal movement is necessary. This modeling approach allows simple model equations, but suppresses the influence of the dynamic wheel load.

With the non-linear single-track model, the vehicle is considered to be a rigid body, which can move only horizontally. Pitch, roll and vertical movements are not modeled and the steering movements are limited to the front axle only. It divides the established equations generally in geometric equations, equilibria and material laws.

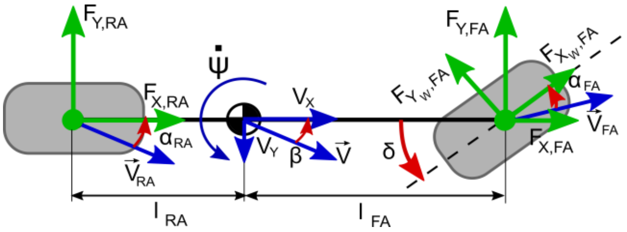

Fig. 6: Terms in single-track model

With the geometric equations, the skew angles of the axes α_{FA} and α_{RA} are determined. They depend on the steering angle δ, the speeds V_x and V_y, the yaw rate $\dot{\psi}$ and the center of gravity as well as l_{FA} and l_{RA}:

$$\begin{aligned} \alpha_{FA} &= \delta - \arctan \frac{V_y + \dot{\psi} \cdot l_{FA}}{V_x} \\ \alpha_{RA} &= -\arctan \frac{V_y - \dot{\psi} \cdot l_{RA}}{V_x} \end{aligned} \tag{1}$$

Furthermore, the float angle is determined in the center of gravity via the following geometric equation depending on the speeds V_x and V_y.

$$\beta = \arctan \frac{V_y}{V_x} \tag{2}$$

The equilibrium conditions are established in all unlocked degrees of freedom. This results in the movement in the horizontal plane, the equilibrium of forces longitudinally and transversely and the equilibrium of moments about the vertical axis.

$$\begin{aligned} ma_x &= F_{x,RA} + F_{x,FA} + m \cdot V_y \cdot \dot{\psi} \\ ma_y &= F_{y,RA} + F_{y,FA} - m \cdot V_x \cdot \dot{\psi} \\ J_z \ddot{\psi} &= l_{FA} F_{y,FA} - l_{RA} F_{y,RA} \end{aligned} \tag{3}$$

The resultant force on the front axle can be represented in the vehicle-fixed or in wheel-fixed coordinate system. The relationship about the wheel steering angle δ is represented by the following set of equations:

$$\begin{aligned} F_{x,FA} &= F_{x_W,FA} \cos\delta - F_{y_W,FA} \sin\delta \\ F_{y,FA} &= F_{x_W,FA} \sin\delta + F_{y_W,FA} \cos\delta \\ F_{x,RA} &= F_{x_W,RA} \\ F_{y,RA} &= F_{y_W,RA} \end{aligned} \tag{4}$$

The lateral Forces $F_{Y,\,FA}$ and $F_{Y,\,RA}$ at the axles can been evaluated via the material properties of the tires, proportional to the slip angles α_{FA} and α_{RA}:

$$\begin{aligned} F_{y_W,FA} &= c_{FA} \alpha_{FA} \\ F_{y_W,RA} &= c_{RA} \alpha_{RA} \end{aligned} \tag{5}$$

Since the tires are summarized in the single-track model, the constant stiffness c_{FA} and c_{RA} are named as axis skew stiffness.

With a conventional tire and at low slip angles (α<3°) the lateral tire stiffness can be assumed to be constant. Conversely, this assumption means that the linear single-track model is valid for vehicles up to a lateral acceleration of approximately 3.5 m/s^2.

Three degrees of freedom describe the motion of the vehicle, a further degree of freedom is the rotation of the front wheel steering. This degree of freedom is used only for applying a skew angle in the set of equations (1) and is restricted by constraints with the steering wheel controls. With the equations (5) the lateral tire stiffness transverse forces can be obtained therefrom. These interact with the equations of equilibrium (3) to the three degrees of freedom of the vehicle.

4.2 Test cases

The sensor concept is tested under two different conditions. In both scenarios the mass of the towing convoy is 627,000 kg (Wide Body TaxiBot plus Airbus A380 at MTOM).

The first test case should represent the push back with a speed of 1.4 m/s. The primary objective of the sensor detection will be put to the smallest possible moving objects. In this case, these are people around the aircraft at close range. For this, the human being is simplified to a square volume, which has the dimensions of 50's percentile of a standard male person [13] (1.75 m x 0.28 m x 0.48 m).

The focus of the second test case is the maximum speed operation of the loaded TaxiBot at 12 m/s at the red marked areas of Fig. 2. Walking persons are not expected in these areas. Due to this fact it is legit to change the size of the object to a small car (e.g. follow me vehicle). The dimensions of this object are set to 1.68 m x 3.74 m x 1.48 m.

The velocity of 12 m/s is the maximum convoy speed at straight sections and is reduced at bad surface conditions.

The simulation of the sensors is represented by the resolution, update frequency and maximum range. The values for each sensor are given in the following.

The scan resolution of the 3D laser scanner depends on the rotation speed and the angular adjustment. By using the scanner which has been built by Fraunhofer Institute IAIS [10] the following specification are applicable: At an angular adjustment of 60° and a rotation at 0.45 Hz we obtain a vertical resolution of 0.5° and a horizontal resolution of 1.7° with an update frequency of 0.9 Hz. At this setting, the maximum range is 80 meters.

The stereo camera covers a 50-degree horizontal field of vision and can take measurements in 3D at a distance of over 50 meters. It has a video signal resolution of 1,280 by 960 pixels and can also process high-contrast images. The signal processing shall provide an update frequency of at least 45 Hz.

4.3 Results

As described two test scenarios were tested in the simulation.

The first scenario represents the pushback with a maximum speed of $V = 1.4$ m/s. The Object is represented by a size of a human being (see chapter 4.2). The simulation showed a residual distance to the object by radar detection of $\Delta X = 6.7$ m and $\Delta X = 32.3$ m at the recognition by the stereo multipurpose camera. In case of contaminated taxiways and movement areas the remaining distance reduces at both sensors by 0.5 m.

The second scenario uses the same sensors under different speed and ambient conditions. In this test case, the cross-section of a small car was recognized by both, the radar and the stereo multipurpose camera system, as well, so that the TaxiBot convoy reached the full stop condition prior to a contact with the obstacle. The distance of the convoy to the obstacle after the detection of the SMPC system is approximately $\Delta X = 179$ m. Due to the sensor characteristics, the remaining distance to the object after the radar detection varies between $\Delta X = 19.5$ m and 30.3 m. This represents at least an additional reaction time of about 1.5 s. This wide range is caused by the relatively poor update rate of the radar image. In case of a contaminated taxiway, the coefficient of friction is reduced to $\mu = 0.3$. Even under these conditions, the remaining minimal distance between the object and convoy is $\Delta X = 3.5$ m.

Thus, the SMPC and the radar sensor are capable to meet the minimal requirements.

5 Conclusions

The autonomous TaxiBot operation appears especially through the efforts of the automotive industry in terms of autonomous driving and sensing technologies feasible at airports in the future. Advantageous is the fact that the route network at an airport is much less complex than the road network. Further lines, signs and markings are consistent and unique at an airport, so that image recognition and a following spatial allocation are facilitated. With regard to the problematic GNSS coverage in backyards in complex terminal architectures this may facilitate the positioning of the convoy.

The sensor concept is designed to guarantee a sensor redundancy and thus error robustness within the in Section 3.1 derived minimal stopping distances.

The simulation result shows that the sensor concept meets the requirements of the TaxiBot-System. However, in case of an increased taxi speed, the concept would have to be adapted. Radar systems from the automotive sector could play a decisive role. These are generally designed for higher velocities, but do not cover the entire surroundings of the TaxiBot. Thus, these are being considered only as additional sensors.

To enhance the vision in low-visibility conditions, the concept contains an infrared camera.

The general ZETO concept encompasses a digital datalink, which is used to exchange position information with the A-SMGC-System. These data allow a validation of the detected objects by the TaxiBot sensors.

6 Acknowledgments

The authors wish to greatly acknowledge the project partner of ZETO, the Institute of Flight Systems and Automatic Control of the Technische Universität Darmstadt, namely Torben Bernatzky, Sebastian Baumann and Uwe Klingauf contributing to the described work.

The project ZETO is funded by the Federal Ministry for Economic Affairs and Energy of Germany, grant number 20E1305B.

7 Contact Author Email Addresses

Sebastian Frank
s.frank@tu-braunschweig.de

Per Martin Schachtebeck
p.schachtebeck@tu-braunschweig.de

Peter Hecker
p.hecker@tu-braunschweig.de

Copyright Statement

References

[1] Eurocontrol. *Challenges of growth 2013, Task 4: European Air Traffic in 2035*. Eurocontrol, Brussels, Belgium, 2013.

[2] Schaufele R. D. jr. et al.. *FAA aerospace forecast, fiscal years 2016-2036*. Federal Aviation Administration, Washington, DC, USA, 2016.

[3] European Union. *FAA Flightpath 2050 - Europe's vision for aviation, report of high level group on aviation research*. European Union, Luxembourg, 2011. doi: 10.2777/50266

[4] Advisory Council for Aviation Research and Innovation in Europe. *Strategic research & innovation agenda, Vol. 1*. ACARE, Brussels, Belgium, 2012.

[5] SESAR consortium. *The ATM target concept – D3*. DLM-0612-001-02-00. SESAR consortium, Toulouse, France, 2007.

[6] Bernatzky T, Baumann S and Klingauf U. Scenario Development for trajectory-based operations enabled by dispatch towing technologies. Accepted paper at the *30th Congress of the International Council of the Aeronautical Sciences (ICAS 2016)*, Daejon, Korea, 2016.

[7] Smith A. *IAI awards Ricardo contract to support next phase of TaxiBot development*. Press Release, url: http://www.ricardo.com/en-GB/News--Media/Press-releases/News-releases1/2011/IAI-awards-Ricardo-contract-to-support-next-phase-of-TaxiBot-development/, accessed: 08/06/2016, Ricardo plc, Shoreham-by-Sea, UK, 2011.

[8] Ford J. Plane savings on the deck; reducing the impact of taxiing. *Online article*, url: https://www.theengineer.co.uk/plane-savings-on-the-deck-reducing-the-impact-of-taxiing/, accessed: 28/06/2016, Centaur Communications Ltd, London, UK, 2016.

[9] i-HLS. Robotic pilot-controlled towing tractor for passenger jets? No longer science fiction. url: http://i-hls.com/2014/11/robotic-pilot-controlled-towing-tractor-passenger-jets-longer-science-fiction/, accessed: 28/06/2016, i-HLS, Israel, 2015

[10] Maurelli F. et al., A 3D Laser Scanner System for Autonomous Vehicle Navigation, *Proceedings of Advanced Robotics ICAR 2009*, IEEE, Munich, Germany, 2009.

[11] Lagisetty R. Object Detection and Obstacle Avoidance for Mobile Robot using Stereo Camera, *IEEE International Conference on Control Applications (CCA)*, Hyderabad, India, USA 2013

[12] Min J. Geometrically inspired MRF for moving object detection from mobile stereo camera, ELECTRONICS LETTERS Vol. 48, IET, 2012

[13] Jürgens H. W., *Collection anthropometric data for updating the DIN 33402*, Deutsches Insitut für Normung, Dortmund/Berlin/Dresden, Germany, 2004