Development and Implementation of a Language Technology System in Air Traffic Controller Student Training

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***Abstract*—**Air The task of air traffic control is to maintain a safe, orderly and expeditious flow of air traffic and to provide advice and information useful for conduct of flights. Air traffic control students undergo a complex and extensive training before they start working on the live frequency. This paper proposes development and introduction of a language technology system in the learning and training process - the proposed system should spot deviations from the standard usage of prescribed radiotelephony language. The system consists of Radiotelephony Phraseology Corpus, Acoustic and Lexical Model for Automatic Speech Recognition for English Language Using Hidden Markov Model Toolkit Tools and System for Control of Radiotelephony Communication Using MATLAB Software Package. The corpus consists of altogether 25828 words and 1733 distinct words. The result of recognition of acoustic and lexical model for automatic speech recognition on the word level and the sentence level is 100%. It correctly recognizes continuous speech of different speakers and transforms uttered messages into a written text. System for control of radiotelephony communication recognizes and reports the deviations from the prescribed radiotelephony communication but does not recognize errors that occur during readbacks.

***Keywords*—**air traffic control training, technology in education, air traffic control communication, radiotelephony phraseology corpus, automatic speech recognition, system for radiotelephony communication correction

I. Introduction

AIR traffic control is a high risk environment. A lot of effort has been put into air traffic controller student training and skill acquisition process. Thought the entire training, air traffic controller students take part in various simulator exercises where they acquire skills and knowledge on procedures in simulated airspace, learn about characteristics of a certain airspace, master how to detect and solve potential conflicts between aircraft, learn how to use equipment on their working positions, etc.

During the simulator exercises, student learn how to communicate in prescribed and specialised radiotelephony language. Radiotelephony phraseology provides means by which air traffic controllers and pilots communicate. It is an organised system for transmission of information, advice, instructions, clearances and permissions.

This paper proposes development and introduction of a language technology system in the leaning and training process. The proposed system should spot deviations form the standard usage of prescribed radiotelephony language. It could make communication between air traffic controller and pilot more efficient and reliable and could therfore contribute to the increase in safety of aviation. This paper is divided into six sections: 1. Introduction, 2. Air Traffic Controller's Training, 3. Air Traffic Control, 4. Air Traffic Control Communication, 5. Language Technology System, and 6. Conclusion.

II. Air Traffic Controller's Training

Air traffic controller's (ATCO) training is defined by international and national regulations that prescribe minimum requirements for the training. ATCO training is divided into four different phases – Initial Training, Unit Training, Continuation Training and Development Training. Each phase and segment of the training is characterized by specific requirements. Initial training consists of basic training and rating training.

Basic Training, provides theoretical knowledge and practical skills to enable an ab initio candidate to progress to more specialized Rating Training. The Rating Training provides knowledge and skills related to a job category and appropriate to the discipline to be pursued in the ATS environment [1]. It consists of theoretical subjects, practical subjects and simulator training.

The Unit Training is divided into three parts: Transitional Training, Pre- On-the-Job Training and On-the-Job Training.

Transitional Training provides site-specific theoretical knowledge and ensures development of skills through the use of site-specific simulations and training.

Pre-On-the-Job Training (Pre-OJT) is locally based training during which extensive use of simulation using site-specific facilities will enhance the development of previously acquired routines and abilities to an exceptionally high level of achievement [1].

On-the-Job Training - OJT is integration in practice of previously acquired job-related routines and skills under the supervision of a qualified On-the-Job Training Instructor (OJTI) in a live traffic situation [1].

Continuation Training is designed for already licensed or certificated air traffic controllers in order to increase and improve existing knowledge and skills. It consists of refresher training, emergency training and conversion training. The last phase of ATCO training is development training. It is designed for ATCOs who would like to make a change in job profile (new license) or who would like to make a career change and start working as a supervisor, safety manager, assessor, etc.

Throughout the whole training, simulation devices are used to acquire skills and demonstrate knowledge. Different exercises are created for each segment of the training according to prescribed minimums for air traffic controller training by International Civil Aviation Agency.

ATC training simulators provide an efficient supplement to theoretical training and training on the job. By gradually increasing the complexity of the training scenarios, students can be confronted with situations tailored to their growing skills. Emergency scenarios hopefully never encountered in reality may be generated without imposing hazards upon real aircraft. Training simulators are also used to maintain the skills of experienced controllers in critical situations.

Air traffic control simulators are also used for research purposes. This helps to test and evaluate new ATC concepts and systems throughout the design phase and before introduction into operational service.

A company training program on pilot-controller communications should strive to involve both flight crew and ATC personnel in joint meetings, to discuss operational issues and, in joint flight/ATC simulator sessions, to promote a mutual understanding of each other's working environment, including:

(a) Modern flight decks (e.g. flight management system reprogramming) and ATC equipment;

(b) Operational requirements (e.g. aircraft climb, descent and deceleration characteristics, performance, limitations); and,

(c) Procedures for operating and threat and error management (e.g. standard operational

procedures [SOPs]) and instructions (e.g. Crew Resource Management).

Special emphasis should be placed on pilot/controller communications and task management during emergency situations [4].

Air traffic control simulators are also used for research purposes. This helps to test and evaluate new ATC concepts and systems throughout the design phase and before introduction into operational service. The results of the simulations permit the assessment of system performance and usability and the identification of weak points, so that the system can be enhanced accordingly. Also, research simulation facilities are used to scrutinize the mental processes involved in the work of air traffic controllers. Simulations allow for the generation of scenarios according to the specific scope of the investigation and the reproduction of these scenarios if necessary [4].

III. AIR TRAFFIC CONTROL

According to the European Organization for the Safety of Air Navigation (EUROCONTROL), air traffic controllers are responsible for guiding aircraft through the airspace safely and efficiently. The goal of Air Traffic Control is to minimize the risk of aircraft collisions while maximizing the number of aircraft that can fly safely in airspace at the same time [5]. The pilots flying the aircraft through the airspace are obliged to precisely follow the instructions of the air traffic controllers. Air traffic control is a combination of four general elements:

a. The first element is the basic set of flying rules that pilots follow in the air.

b. The second element is the multitude of electronic navigation systems, landing system and instruments that pilots use.

c. The third element is the division of airport surface and air space in different type of control areas. Air traffic controllers operating in each of these areas and the computer systems they use to track aircraft during take-off, landing and in flight are also part of this element.

d. The fourth element is the communication between pilots-controllers, controllers-controllers and the equipment used for this communication [5].

Every flight is divided into seven different phases (Fig. 2): pre-flight, take-off, departure, en-route, descend, approach, and landing. Throughout the whole flight, pilots are in a constant and continuous voice communication with air traffic controllers. Each phase of flight is defined by what the plane does and is handled by a different controller.

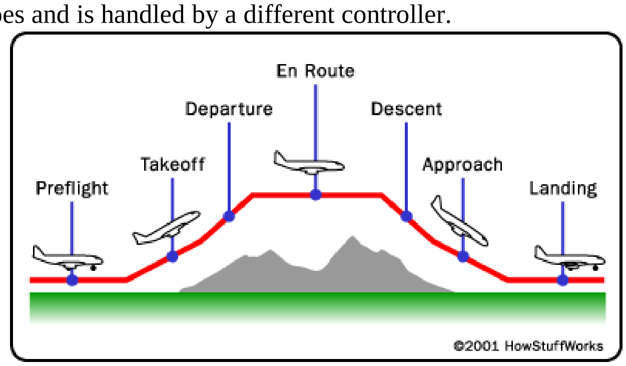

Fig. 1 Phases of flight [2].

As it is defined by Annex 11 (ICAO, 2001) to the Convention on International Civil Aviation, objectives of air traffic control services are:

• to prevent collisions between aircraft in the air and on the maneuvering areas of aerodromes

• to prevent collisions between aircraft and other vehicles and obstructions on the maneuvering area of aerodromes

• to maintain a safe, orderly and expeditious flow of air traffic

• to provide advice and information useful for the safe, orderly and expeditious conduct of flights.

To fulfil all the mentioned objectives, air traffic control services have to be in constant communication. Different types of communication are used to provide information in air traffic control, however the most significant one is voice communication.

IV. Air Traffic Control Communication

Voice communication is one of the most vital parts of air traffic control. It helps pilots and air traffic controllers operate the plane and maintain safe and expeditious flight. Throughout the years, investigations of many accidents and incidents have found that lack of radiotelephony proficiency and discipline by pilots and controllers has been a major causal factor.

The purpose of the communication between a pilot and an air traffic controller is to synchronize air traffic controller's decisions through utterances with what pilot does to an airplane. Pilots and air traffic controllers communicate in English using prescribed radiotelephony phraseology. It is a set of prescribed rules what to say, how to say, when to say something, and how to understand uttered. It is an organized system for transmission of information, advice, instructions, clearances and permissions from the sender to the receiver and vice versa. If it is used properly, it insures safe and expeditions flow of traffic, but if not used properly it can lead to a misunderstanding and even a disaster.

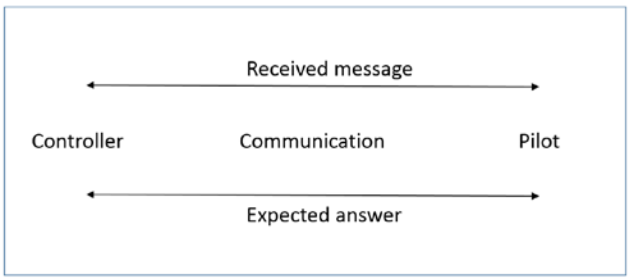

Fig. 2. The purpose of pilot – controller communication.

Pilot – controller communication has a specific flow and it is characterized by a specific communication loop. This communication loop follows this pattern:

1. The controller utters an instruction or a clearance through a headset system.

2. The pilot receives the instruction or a clearance through the headset system, acknowledges the receipt of the message and replies.

3. The controller carefully listens to the message transmitted and uttered by the pilot, following if all the mandatory pieces of information are repeated and understood correctly.

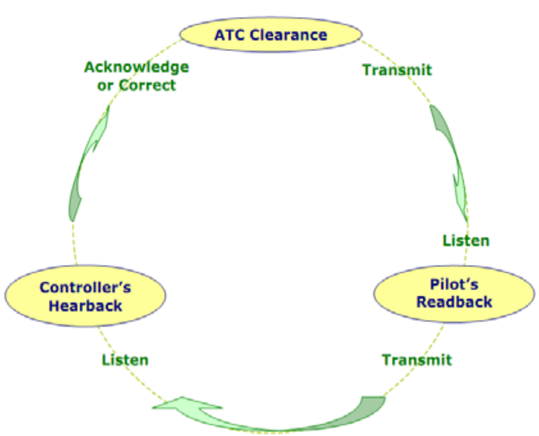

Fig. 3 The pilot – controller communication loop [7].

As prescribed by ICAO Annex 10, safety-related part or parts of any clearance or instruction have to be readback to the air traffic controller. The part or parts of a clearance or instruction that always have to be readback are taxi instructions, level instructions, heading instructions, speed instructions, airways/route clearances, approach clearances, runway in use, all clearances affecting any runway, SSR operating instructions, altimeter settings, VDF information, type of radar service and transition levels [3].

Additionally, information contained in the clearances or instructions should be grouped and should follow chronological order of actions. Also, the number of instructions or clearances in the transmission should be limited.

In order to maintain high levels of safety and to ensure correct and timely communication, pilots always have to read back instructions received from air traffic controllers and controllers have to listen to the readbacks and confirm them. The pilot – controller confirmation – correction process is a loop that ensures effective communication and serves as a defense against communication errors.

It is important to mention that the environment in which pilot – controller communication takes place is a time – sensitive environment. Pilots and controllers cannot see each other or each other actions, therefore an important means of error detection is unavailable.

Non-standard, incorrect or incomplete radiotelephony phraseology is a major obstacle to effective communication and is an important means of accident and incident prevention because:

1. Standard phraseology in pilot-controller communication is intended to be universally understood.

2. Standard phraseology helps lessen the ambiguities of spoken language and thus facilitates a common understanding among speakers:

(a) Of different native languages; or,

(b) Of the same native language, but who use, pronounce or understand words differently.

3. Non-standard phraseology or the omission of key words may completely change the meaning of the intended message, resulting in potential traffic conflicts.

4. For example, any message containing a number should indicate what the number refers to (e.g. a flight level, a heading or an airspeed). Including key words prevents erroneous interpretation and allows an effective readback.

5. Particular care is necessary when certain levels are referred to because of the high incidence of confusion between, for example, FL100 and FL110.

6. Non-standard phraseology is sometimes adopted unilaterally by national or local air traffic services, or is used by pilots or controllers in an attempt to alleviate these problems; however, standard phraseology minimizes the potential for misunderstanding [6].

V. Language Technology System

In order to improve radiotelephony communication and training, a research was carried out to look into communication flow within air traffic control, to spot and define communication problems and to develop and propose a language technology system that could spot deviations from the usage of standard phraseology and warn about incorrect readbacks.

The usage of proposed language technology system should make communication between air traffic controller and pilot more safe, efficient and reliable and could contribute to an increase in safety of aviation. This language technology system should detect at least 80% of errors, regarding used language and numbers, in communication between pilots and air traffic controllers.

According to the interviews with the instructors of radiotelephony communications at the Faculty of Transport and Traffic Sciences in Zagreb and air traffic control instructors, the largest portion of communication between a pilot and an air traffic controller takes place during approach and landing. Therefore, this proposed system is created, tested and should be in the future applied in the student's training for Approach and Tower Control Units. The language technology system is designed to be firstly used and tested as a part of student's training on the simulator. Once when it is tested and upgraded it could even be implemented in live air traffic control communication.

The system should be used for detecting two groups of problems:

1. language-based communication problems (unfamiliar radiotelephony phraseology, incomplete or incorrect readback/hearback utterances)
2. communication problems with numbers (altitude, heading, altimeter setting, frequency setting, etc.).

The proposed language technology system consists of three different parts and is developed in three stages:

1. radiotelephony phraseology corpus
2. acoustic and lexical model for automatic speech recognition for English language using *Hidden Markov Model Toolkit tools*
3. system for control of radiotelephony communication using MATLAB software package.

The proposed language technology model that has been built and is described in this paper includes standard phrases and procedures related to routine situations.

A. *Radiotelephony Phraseology Corpus*

The first prerequisite for setting up the language technology system was compilation of radiotelephony communication corpus. The recorded corpus along with prescribed radiotelephony phrases gives an overview of the "live" language that is used by air traffic controllers and pilots.

The corpus is designed from three different groups of data. The first group consists of 556 standard radiotelephony phrases prescribed by Radio Communication Procedures. The second group is designed from transcripts of the recordings (ten hours of communication from Zagreb Approach Control and ten hours of communication from Zagreb Tower Control) and contains 1967 exchanges. The recordings were collected during November and December 2012 and January 2013. The third set of data contains terminology used at airports (e.g. names of airport vehicles, names of runways and taxiways at Zagreb airport, etc.), information relevant for Croatian airspace (waypoints, routes, etc.) and information on procedures that are carried out at Zagreb airport.

The radiotelephony corpus was designed and analyzed with *Oxford WordSmith Tools 04* (2007). *Oxford WordSmith Tools 04* was used to create a list of all words and word forms that are included in the compiled corpus and accompanying statistical data.

The corpus consists of altogether 25828 words and 1733 distinct words. The first ten most frequently used words in the corpus are numbers – the most frequent word in the corpus is zero. It appears 1375 times. The next one is the word one. The first most recurrent lexical word, besides numbers and prepositions, is runway. All extracted words and word forms were used to later create acoustic and lexical model for automatic speech recognition.

The corpus of radiotelephony phraseology can be described as follows:

a) It is representative – the corpus contains texts of the same register and content (text of radiotelephony communication). The findings from the corpus are generalizable and applicable to any European radiotelephony language.

b) In terms of the content – it contains standard radiotelephony phrases prescribed by Radio Communication Procedures, transcripts of radiotelephony communication recordings and terminology used at airports, information relevant for Croatian airspace and information on procedures that are carried out at Zagreb airport.

c) It can be described as a static corpus – for the moment; this feature may have an influence on the corpus representativeness, so the plan is to extend and upgrade the corpus of radiotelephony communication for future research.

B. *Acoustic and Lexical Model for Automatic Speech Recognition for English Language Using Hidden Markov Model Toolkit Tools*

The second stage of the language technology system construction is the development of the acoustic and lexical model for automatic speech recognition for English language using Hidden Markov Model Toolkit tools. The steps and procedures of making an acoustic and lexical model listed in the book *The HTK Book* (*for HTK Version 3.4*, 2009) and the corresponding version of the tool were used to develop the model. The role of this model for automatic speech recognition is to recognize continuous speech of different speakers and to transform an uttered message into a written text.

The content of the acoustic and lexical model for automatic speech recognition is the language of radiotelephone phraseology which is carried out in English, so the model was built according to the phonetic and linguistic rules of the

English language. It contains the phrases collected in the radiotelephony phraseology corpus, phrases that are used on the frequency, code names such as signifiers of important points for the airport Pleso. The term used for greetings in Croatian, German, French, and so on, were also added to the model and transcribed also according to the phonetic and linguistic rules of the English language.

The automatic speech recognition model was developed in four steps - data preparation, training, testing and analysis of the results. In the first step, the vocabulary, that needs to be recognized, was defined. The speech samples for learning and testing were recorded. The transcriptions of the recorded materials were prepared. The raw speech waveforms were parameterized.

650 speech samples were recorded, containing 500 samples of sentences in general English and 150 sentences of radiotelephone phraseology also in English. A dictionary containing 2,015 terms was built.

The prepared speech training samples and transcriptions were reestimated in the second step. In the third step, the model was tested on 50 recorded samples of radiotelephony phraseology. Finally, the last step is results analysis. The test results were compared with the reference transcriptions. The results show that all 50 samples were recognized correctly. The result of the recognition on the sentence level is 100% (out of 50 utterances used for testing, 50 were correctly recognized and 0 wrongly). The result of recognition on the word level is 100%. Out of 557 words, 557 words were correctly recognized, there were 0 deletion, 0 substitution and 0 insertion errors.

The built model for automatic speech recognition of radiotelephony phraseology language correctly recognizes continuous speech of different speakers and transforms uttered messages into a written text.

C. System for Control of Radiotelephony Communication Using MATLAB Software Package

The final phase of the language technology system development was building a system for control of radiotelephony communication using MATLAB software package. The created system compares the pronounced with the prepared base of standard radiotelephony phrases, which are prescribed by Radio Communication Procedures and phrases recorded on the frequency. The system warns the user if there are any deviations from the prescribed usage of radiotelephony phraseology or the data exchanged in communication.

As a basis for programming, 32 tables with phrases from the compiled corpus were created. Every table is named according to the stage of flight during which certain phrases are used. The phrases prescribed by Radio Communication Procedures and phrases collected from the transcripts of the recordings of communication from Zagreb Approach Control and Zagreb Tower Control are contained in the tables. They are organized in a form of a dialogue. 1718 different call signs, names of arrival and departure procedures, name code designators and ICAO phonetic alphabet are also added to the tables.

After the data preparation, software for control of radiotelephony communication was programmed in MATLAB 8.2 (2013). A working directory for the analysis of pilot’s and air traffic controller’s dialogue was created. Pilot’s and air traffic controller’s uttered dialogues were recognized and transcribed by HTK and compared with the phrases form the tables. Nine dialogues, simulating communication in approach and tower control, were prepared and recorded for the testing. The dialogues were marked with numbers (D1, D2, D3), the person who pronounces the phrase (P for pilots and A for air traffic controllers) and the number indicating the sequence of a phrases in a dialogue:

D1A1 Turkish Airlines Five Mike Whiskey, Report Heading.

D1P2 Turkish Airlines Five Mike Whiskey, Heading Two Three Zero.

D1A3 Turkish Airlines Five Mike Whiskey, Fly Heading Two Three Zero, Descend to Five Thousand Feet, Vectoring for ILS Approach Runway Zero Five.

D1P4 Heading Two Three Zero, Descending to Five Thousand Feet, ILS Approach Runway Zero Five, Turkish Airlines Five Mike Whiskey.

D1A5 Turkish Airlines Five Mike Whiskey, Turn Right Heading Zero Two Zero, Cleared ILS Approach Runway Zero Five, Report ILS Established.

D1P6 Turning Left, Heading Zero Two Zero Cleared ILS Approach Runway Zero Five Wilco, Turkish Airlines Five Mike Whiskey.

D1A7 Turkish Airlines Five Mike Whiskey, Correct.

In five dialogues there are no deviations from the prescribed radiotelephony communication and no errors that occur during readbacks, and in four dialogues there are deviations from the prescribed radiotelephony communication and some errors that occur during readbacks.

As expected, for dialogues in which there are no deviations from the prescribed radiotelephony communication and no errors that occur during readbacks, the system does neither detect nor report any errors.

The system recognises if the pilot or controller utters a certain phrase. It also, in most of the cases, recognises the phase of the flight in which a certain phrase is used. Sometimes, the system identifies the correct usage of the phrase, but it does not recognise the correct phase of the flight.

The results for four dialogues in which there are deviations from the prescribed radiotelephony communication and some errors that occur during readbacks were only partly satisfactory.

The system recognises and reports the deviations from the prescribed radiotelephony communication but does not recognise errors that occur during readbacks (altitude, runway designator, frequency, etc.).

VI. Conclusion

An important part of air traffic controller's training are simulators. Throughout the whole training, air traffic control students pass different stages of training on simulation devices. They are used to acquire skills and to demonstrate knowledge. They are also used to maintain the skills of experienced controllers.

Development and implementation of suggested communication technology system would be a valuable asset in the training of future and current air traffic controllers. The results of the testing show that it is necessary to connect dialogue sequence better (the used phrases with the previous or next phrase used in a dialogue) so that the system is able to recognize the readback errors better and is able to identify the phase of flight in which a phrase is used.

The proposed model should be further upgraded and tested on the recordings form communication on the frequency, during student's simulator exercises and finally in real air traffic communication environment. Once when the system is tested and approved it can be expanded to other air traffic control units.

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