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Model-Driven Framework for Design and Production of Low-Budget Stereoscopic TV Content

Aleksandar Spasić
(College of Professional Studies for Pre-School Teachers, Pirot, Serbia
aspasic@string.co.rs)

Dragan Janković
(University of Nis, Serbia
dragan.jankovic@elfak.ni.ac.rs)

Abstract: Three-dimensional television (3D TV) is expected by many to be the next step in the advancement of television. Due to significant financial exhaustion during the process of transition from analogue to digital production, low-budget broadcasters are not in the position to invest in a new 3D system. This paper proposes one model-driven framework approach to 3D TV production system applicable to and suitable for low-budget broadcasters.The target of the project is to define one of the possible scenarios for applying stereoscopic 3D technologies to low-budget TV production. 3D TV content production chain is described in the first step of the project. 3D TV production workflow is proposed in the second step. This step has two parts: the analyses of the production stages and their integral processes, and the definition of a problem space model which is suitable for low-budget 3D TV production. The preproduction, production and postproduction phases of a low-budget 3D TV production are described during the analyses of 3D TV content production workflow. The UML is used as a modelling tool. The behavioural description of a program production is modelled by the Use Case diagram. A state machine diagram is used to describe the dynamic behavioral representation and the life cycle of a 3D content. The flow and dependencies in 3D workflow are modelled by using the activity diagrams. The structural static representation (domain model) is presented by a class diagram.

Keywords: Computing Independent Model (CIM), 3D TV production, Model of Problem Space (MOPS), Software Intensive System of 3D Television Production
Categories: H.1.0, H.4.0, D.2.1, D.2.9, K.6.1, K.6.4

1 Introduction

Technological changes dramatically altered the way in which television programs are produced and distributed. Due to the convergence of traditional broadcasting and information technology, the pace of changes in the television industry accelerates dramatically. Three-dimensional television (3D TV) is expected by many to be the next step in the advancement of television [Ozaktas, 08], [Onural and Ozaktas, 08], [Tam and Zhang, 06] and it is one of the hottest subjects in the media world today. Many alternative systems have been developed for what is known as the'First Generation 3D TV' [De Geyter and Overmeire, 09]. Broadcasters in different parts of the world have announced their intention to start 3D TV broadcasting. There are test broadcasts currently available via satellite. Among other events, certain football matches in the 2010 World Cup were shot in 3D TV [DVB, 10a].

1.1 Paper Aims and Research Method

The independent media, local and regional broadcasters are, if not the only, then certainly the most essential and forceful segments of a democratic structure of the society [Spasic and Nesic, 09], [Spasic and Nesic, 05a]. In addition to imparting information, they also play an important cultural and educational role, since their example demonstrates the use of the basic postulates of the modern world – the freedom of the press, thought and expression.

The value and cost of digital broadcast equipment are now primarily related to the software rather than hardware. However, the marketing model for broadcast equipment is still based on loading the entire development and support cost into the hardware. This model is outdated and serves neither the manufacturer nor the purchaser.

In search of a solution, low-budget program makers have quickly discovered that there is no existing model within the 3D broadcast and production industry to which they can turn. The current “off-the-shelf” expensive 3D digital production solutions rarely offer that which the typical local or regional media enterprises need – a simplified and inexpensive 3D production. Ultimately, what is needed is a complete rethinking of the way in which technology can be applied to the art and business of 3D program making and low-budget broadcasters should reconsider alternatives to partial in-house developments.

The primary aim of this paper is to propose one model-driven approach to 3D TV production system applicable to and suitable for low-budget broadcasters. The target of the project is to figure out one of the possible future scenarios for applying stereoscopic 3D technologies to low-budget TV production.

The first step of the project is to describe the whole 3D TV content production chain, from the initial idea and acquisition, through processing and visualization, to final archiving and delivery.

The second step is to propose one 3D TV production workflow. This step is divided into two parts. The first part is to analyse the production stages and their integral processes and the second part is to define the problem space model which is suitable for low-budget 3D TV production.

There are not many workflow models of the multimedia production system, especially workflow models for stereoscopic multimedia. Thus, workflow automation and metadata interoperability between different workflow steps is of growing importance. Some of the previous works have analysed the metadata needed for the audiovisual media production process and an automation workflow based on workflow languages has been proposed, e.g. for movie production in the YAWL4Film project [Ouyang et al., 08]. In [Badii et al., 09] and [Badii et al., 10] software engineering methods which are being applied to media production using UML and YAWL have also been proposed. In the above mentioned papers the main focus was on the stereoscopic cinema. Therefore, the workflow proposed here is suitable for low-budget stereoscopic production and it allows for the inclusion of different types of stereoscopic content, such as documentary or sport.

The third step in the research, which has not been included in this paper but which uses the results described here, entails developing a workflow model based on Generalized Nets (GN). This step is described in [Spasic, 13].

Software-intensive 3D TV production system can be considered a multimedia information system and a development practice applicable to that type of information systems should be applied [Barry and Lang, 03], [Rout and Sherwood, 99].

Modelling in problem space is used as a research method in this paper. A model is, by its very nature, an abstraction of the reality. Software projects use modelling throughout the entire life cycle. Successful modelling needs to consider the areas in which modelling needs to take place. These modelling spaces have been formally considered and discussed by Unhelkar in [Unhelkar, 05]. Three distinct yet related modelling spaces have been defined: problem, solution and background. These divisions provide a much more robust approach to modelling, as they segregate the models on the basis of their purpose, i.e. whether the model is primarily created to understand the problem, to provide a solution to the problem, or to influence both of these purposes from the background, depending on organizational constraints and the need to reuse certain components and services. The modelling output in such software projects transcends both data and code and results in a suite of visual models or diagrams.

In the Unified Model Language (UML) projects, model of problem space (MOPS) deals with creating an understanding of the problem, primarily the problem that the potential user of the system faces. Though a business problem is the one usually being described, a technical problem can also be described at the user level in MOPS. In any case, the problem space deals with all the work that takes place in understanding the problem in the context of the software system, before any solution or development is attempted. Typical activities that take place in MOPS include documenting and understanding the requirements, analysing requirements, investigating the problem in detail, and perhaps optional prototyping and understanding the flow of the process within the business. Thus, the problem space would focus entirely on what is happening with the business or the user [O'Doherty, 05].

Problem space will need the UML diagrams that help the modeller understand the problem without going into technological detail. Here, the interest has been shown in the UML diagrams that help express what is expected from the system, rather than how the system will be implemented. These UML diagrams in the problem space are as follows [Unhelkar, 05]:

Use Case diagrams—provide the overall view and scope of functionality. The use cases within these diagrams contain the behavioral (or functional) description of the system.

Sequence and state machine diagrams—occasionally used to help us understand better the dynamism and behavior of the problem.

Activity diagrams—provide a pictorial representation of the flow anywhere in MOPS. In MOPS, these diagrams work more or less like flowcharts, depicting the flow within the use cases or even showing the dependencies among various use cases.

Class diagrams—provide the structure of the domain model. In the problem space these diagrams represent business domain entities, not the details of their application in a programing language.

The authors' previous experiences with modelling of problem spaces in television production are outlined in [Spasic, 06], [Nesic et al., 03], [Spasic, 05], [Spasic and Nesic, 05b] and [Spasic et al., 06].

1.2 Theoretical Background of 3D TV Imaging, Transmission and Displaying

The fundamental principle underlying 3D TV conversion techniques rests on the fact that stereoscopic viewing involves binocular processing of two slightly dissimilar images by means of human visual system. The slight differences between the left-eye and right-eye images, known as horizontal disparities or binocular parallax are transformed into distance information such that objects are perceived at different depths and outside of the 2D display plane [Talebpourazad, 10], [Puri et al., 97].

Four general techniques can be used in the implementation of flat-screen display systems able to support the binocular parallax depth cue. These four techniques are outlined in [Blundell, 08]. *Chromatically Coded Images* is the technique used in the formation of the anaglyph images. Here, the left and right views which form the stereo pair are each depicted in a different colour (for example, cyan and red). Filter glasses are used to present each eye with a different view. Thus, for example, the left eye may be presented with a view depicted in red, and the right eye with a view depicted in cyan – only one view being seen by each eye. *Non-Coded Images* is a technique where the left and right views of the stereo pair are depicted side by side. Each image is then directed to the appropriate eye. In this scenario, coding of the images is unnecessary because they are kept apart and presented separately to the visual system. Here, a head-mounted device with two separate display screens is employed: one for the left eye, and one for the right. Thus, the left and right views of the stereo pair are fed directly to the two eyes. *Temporal Coding* assumes that the left and right-hand views of the stereo pair are depicted as alternate frames on a flat screen display. Thus, for example, the first, third, and fifth frames etc. depict one of the images of the stereo pair, and the second, fourth, and sixth etc. frames correspond to the other. In this way a stereo pair is temporally coded (i.e. coded in time). In order to correctly perceive the stereo content, a user must wear special purpose viewing glasses which may be either active or passive. Active glasses receive a synchronisation signal from the computer or display which controls the optical properties of the two eye-pieces. Typically, these comprise liquid crystal based shutters and can be switched between transparent and opaque states. Passive glasses employ polarising filters and are used in conjunction with an active polarising filter that is fitted to the front of the display screen. The objective is to ensure that each of the two images of a stereo pair is directed to the appropriate eye – and cannot be seen by the other eye. In the simplest case, the active linearly polarising filter fitted to the display screen is able to switch between two orthogonal planes of polarisation. The filters fitted to the viewing glasses are arranged so that, for example, the right eye filter will pass only the vertically polarised light and the left eye filter only the light polarised in the horizontal direction. *Spatial Coding* technique can be implemented in various ways but is essentially based on the projection of the left and right images that form the stereo pair into two separate regions such that when an observer is correctly positioned, each eye is presented with one of these views. Here, the left and right views of the stereo pair are each divided into a set of vertical strips and these are displayed in an interleaved manner. A barrier comprising a set of vertical slits lies between the displayed image and the viewer. The pitch of the slits (i.e. the distance between the centres of adjacent slits) is arranged to be approximately the same as the pitch of the interleaved image strips and so when an observer is correctly positioned, the right eye is able to see only one set of strips and the left eye the other set.

The most critical issue today is deciding upon a unique transmission format for the left and right signals, which operate in an HDTV environment. There are a lot of options, and all of them would work [Vetro, 10a], [Vetro, 10b]. The question is whether 3D TV can possibly be a success unless we all converge onto one system.

In terms of compatibility with a conventional 2-D broadcast system a double bandwidth is needed if the video streams are to be transmitted uncompressed. 3D signals can be delivered to the 3D television in several ways. The simplest of these formats are known as frame-compatible: checkerboard pattern and panels (side-by-side or top-and-bottom). The frame-compatible formats are half the resolution of their 2D equivalents.

Additionally, there are ways to store, carry, and transmit the 3D TV video signal which provide full resolution, such as Simulcast, MPEG's Multi-View Coding (MVC) standard and 2D+Depth. Simulcast sends two 2D streams, one for the left eye and one for the right eye; this requires double the bandwidth of a 2D signal. The MPEG Industry Forum is actively promoting an extension of the MPEG-4 AVC/H. 264 standard, which will essentially transmit one "eye" plus the metadata that will define the differences for the other eye. The estimate is that this will add about 50% to the bandwidth requirement over 2D high definition, or conversely will reduce the bandwidth for a two-channel transmission system by 25%. 2D+Depth is predicted to be more bandwidth efficient than MVC but more complex for both encoders and decoders to implement. The present situation and progress expected in stereo and multi-view coding formats and standards are described in [Vetro, 10c] and [Dong and Ngi Ngan, 10].

All possible 3D displays can be divided in four main categories: autostereoscopic, stereoscopic, light-field and volumetric [Longhi, 10], [Pastoor, 05]. Two main types of 3D display technologies available for home user applications today are autostereoscopic and stereoscopic. Autostereoscopic is related to a screen that displays 3D images without using glasses. It uses either a lenticular lens or a parallax barrier in front of a specialized display (usually LCD) presenting a different image to each eye [Shan et al., 04]. While it does not require glasses to see 3D, it has a limited viewing angle as well as a lower effective resolution and can cause eye fatigue and dizziness. Different kinds and sources of visual discomforts during 3D viewing are described in [IJsselsteijn et al., 05].

Stereoscopic technology uses glasses to provide a different image to the viewer's left and right eyes and there are three different types of glasses that are described above.

Generally speaking, there are three generations of 3D TV which will progressively come into play in the years ahead [De Geyter and Overmeire, 09].

First Generation 3D TV, known as stereoscopic television, is a category of system which could be broadcast and is practical today. It is essentially the combination of the left and right eye pictures where the viewer needs glasses, and the left and right pictures are 'fused' by the brain into a picture with depth. It is a perception based subset of natural vision.

Second Generation 3D TV is known as autostereoscopic television. These systems record a large number of signal pairs, and usually present them on a display that does not need glasses (autostereoscopic), providing multiple viewpoints. With the present-day technical systems there are limitations on resolution and viewing position, but they will very soon become practical consumer electronics.

Third Generation 3D TV will integrate imaging and holography. Here we record the entire light field or object wave. No eye fatigue and dizziness. It is commonly believed that we are probably 30 to 50 years away from such systems becoming practical.

1.3 Present Situation in 3D TV Production

The interest of users and content producers in 3D is constantly growing owing to the recent cinema involvement with 3D movies. In the future there will be a lot of contents able to meet the daily user necessities. For these reasons bringing 3D into consumers´ homes is seen as a great market potential. Nowadays, stereoscopic displays and Blu-ray 3D players are next to hit the market and give the first sample of 3D home perception.

The 3D TV we talk about today is usually the one belonging to the First Generation – a stereoscopic television based on two camera images, which have been shot, edited, encoded and delivered to the viewers who are usually offered some arrangement (usually special glasses) to ensure that the left and right eye signals get to the corresponding eye. The main commercial requirement of the present-day 3D TV specification is that broadcasters have access to the existing DVB HDTV broadcast channel, and that viewers have access to the existing or suitably adapted receiver to receive the 3D TV content [DVB, 10b]. Thus, the 3D TV specification can be considered to be a system which can be used with the existing delivery and home infrastructure.

Consumer electronics manufacturers launched 3D TV products during 2010. The following 3D TV consumer configurations are available to the public:

- 3D TV connected to 3D Blu-ray player for packaged media.
- 3D TV connected to HD games console, e.g. PS3 and Xbox360, for 3D gaming.
- 3D TV connected to HD STB for broadcast 3D TV.
- 3D TV receiving a 3D TV broadcast directly via built-in tuner and decoder.

There are very few already completed end-to-end 3D TV systems. Some of them are:

- EC funded 3D TV Projects (2002-2008) [Redert et al., 02], [Onural, 09], [Müller, 09].
- Mitsubishi Electric Research Laboratories (MERL) [Vetro, 10a], [Vetro, 10b]
- ETRI (3D video over T-DMB and S-DMB) [Kim, 08], [Lee et al., 08].

Different associations and organizations have been founded, and not only with respect to 3D standardisation. There are several ongoing projects which should help 3D TV promotion and standardisation, such as 2020 3D [2020 3D media, 10], 3D@Home [Chinnock, 09] or SMPTE Task Force on 3D to the Home [Zou, 09], [Mendiburu, 09a].

The manufacturers of professional television production equipment followed the trends imposed by consumer electronics producers and launched different solutions for complete or partial 3D TV production chain. Commercial solutions available on the market are presented in [Sony, 10], [Thomson, 10], [Harris, 10], [Ericsson, 10], [Panasonic, 10a], [Panasonic, 10b] and [Phillips, 09].

2 Stereoscopic 3D TV Content Production Workflow

Traditional digital HDTV production is based on the workflow which is largely linear in nature. The simplified chain of production is shown in Figure 1. [Hunter et al.,00].

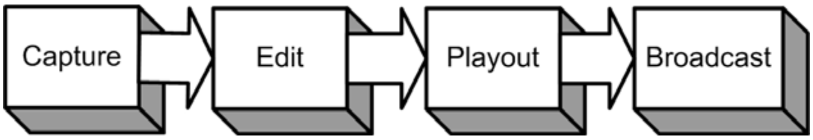

Figure 1: Simplified chain of traditional production

Several different models of production workflow are presented in [Kloth, 10].

The professional video production process usually requires three distinct phases [Davis, 03], [Musburger and Kindem, 09], [Van Tassel and Poe-Howfield, 10]:

1. *Preproduction*: concept formation, scriptwriting, storyboarding and production planning.
2. *Production*: video and audio recording.
3. *Postproduction*: video and audio editing, special effects, soundtrack composition and final assembling.

A production workflow can be scrutinized through various stages [Orlebar, 02]. A program's life begins with scheduling, planning, and research. A producer works within a framework for a specific program which is called a format [Cury, 11]. It defines the opening and closing, the number of commercial breaks, the amount of time for content, and the overall length. In television production a format usually indicates the type of content that will be put in certain segments [Keirstead, 05].

Video shots, audio clips and other program items are created during the acquisition stage. The next stage is editing, when shots, clips, animations and assembled items are put in order. After editing, the program is encoded and sent to the delivery point for transmission or playout. Finally, the program is archived.

One of the most important challenges stereoscopic television has to meet is the backward compatibility with the existing DVB HDTV broadcast channel. This compatibility must be in technical and technological compliance with the existing HDTV standards outlined in [Hartwig, 05], [Benoit, 06], [De Alencar, 09], [Arnold et al., 07], [De Bruin and Smits, 99], [Collins, 01], [Cianci, 07] and [Schmidt, 09]. Low-budget broadcasters recently faced a significant financial exhaustion during the process of transition from analogue to digital production and, at this moment, a large investment in a new system is not an option.

Making good stereoscopic content requires new ways of production grammar and cannot easily be compared with the making of HDTV content. The quality of 3D content is the result of an end-to-end quality assessment throughout the production process. If 3D content was not properly handled at any given point, it would not be possible to fix it later for a reasonable price.

In general, there are four types of 3D content generation [Tam and Zhang, 06]: a) the stereoscopic dual-camera approach, which results in two separate views (left and right), b) the 3D depth-range camera approach, which generates a 2D image plus a depth map, c) the 2D-to-3D video conversion approach, which converts the existing 2D video material into stereoscopic 3D by estimating a depth map from the 2D video sequence and subsequently rendering the left and right sequences, and d) the multi view video camera approach. Additionally, computer-generated imaging (CGI) and rendering is possible.

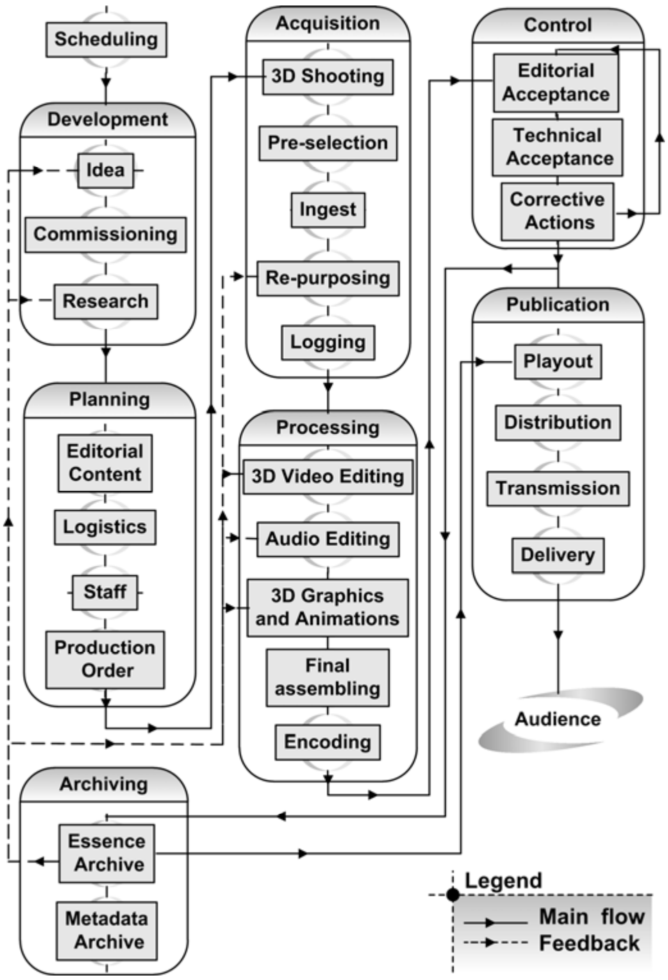

Figure2: 3D Program Production Workflow

The 3D content generation suitable for a low-budget stereoscopic production is an approach which involves simultaneous capturing of stereo paired images, i.e. stereoscopic dual-camera approach.

The basic production stages are defined here as follows: development, planning, acquisition, processing, control, archiving and publication. These stages are shown in Figure 2, along with what the production processes consist of. Metadata can be collected and possibly reused in each step of the production workflow.

2.1 Development

A program's life traditionally begins with a need to fill a slot in a schedule. A new skeleton schedule is based on the analyses of the audience numbers and reactions. This schedule needs to encompass the details of the program categories, the possibilities for reusing (repeat) the programs, as well as a budget outline of the programs required to fit into slots.

The creativity and freedom of directors, producers and editors will suffer some restraints until better 3D production tools are crafted and until the audience gets educated on this new cinematographic language. A cost-justified 3D production will have to appear with actual storytelling gain, or people will stay and see it in 2D. There is a need for a new generation of directors and editors, screenwriters and producers who understand 3D and create their stories with depth. That means that producers should be aware of the visual constraints the stereoscopy imposes on 3D production tools.

A 3D effect has to be modulated throughout the story, and that modulation has to be scripted. A depth script (stereopsis) is only the description of the amount of depth over time. It can be a chart or a text description.

During the development stage, program ideas are thoroughly checked into and when the producer persuades a TV company to finance the conversion of an idea into a real program, a commission is settled. The commission is very important for production as it gathers some key information such as the 'working' title, producer's identity, possibly contributor's names, genre and sometimes the initial scripts. It could well make financial decisions which subsequently apply to the rest of the program making process.

When the commission has been accepted, the research is done and archives and other databases are examined for potential contributors, locations, facilities and material that can be reused.

2.2 Planning

The planning involves staffing and resourcing as well as creating the artistic description in the form of a storyboard and script.

Resourcing has to be properly worked out and budgeted, and that includes everything from casting the onscreen personalities (and their terms for taking part) to the availability, costs, and other details for useful experts, experienced researchers, and production and postproduction personnel. Furthermore, the usage of the equipment has to be planned and budgeted as well.

Before going into 3D production, answers on important organizational and technical questions should be found (how does 3D affect all phases of the production, the issue of new 3D storytelling constraints and relating tools, the stereopsis process and the depth script should be defined, the stereoscopic comfort zone and floating window etc.) [Mendiburu,09b].

At the end of the planning stage a production order may be presented.

2.3 Acquisition

During the acquisition stage, video shots, audio clips and other program items are created, preselected, ingested into production system and logged.

Stereoscopic television is the most prominent and, in a way, the most intelligible type of 3D video representation [Minoli, 10], [Onural, 11]. Only colour pixel video data are involved and captured by at least two cameras. The resulting video signals may undergo some processing steps like normalization, colour correction, and rectification, but in contrast to other 3D video formats, no scene geometry information is involved. In principle, the video signals are meant to be directly displayed by using a 3D display system.

The majority of 3D broadcast material available today has been produced using a twin-lens [Kim, 08] or dual-camera configuration providing a stereo pair where the left-eye and the right-eye views are separately recorded from slightly different perspectives.

The fundamental way to capture a stereoscopic TV signal is to use two cameras mounted on the same axis and separated by the spacing of the average pair of human eyes (6.25cm). Camera spacing can be varied, and cameras can be ‘toed in’, to achieve different elements of picture composition. Filming parameters such as camera base distance (distance between the two cameras), convergence distance (distance from the cameras to the point where both optical axis intersect), and camera lens focal length can be used to scale the horizontal disparity and thereupon the degree of perceived depth.

Stereoscopic capturing requires that both director and camera operator are highly skilled in stereoscopic geometry and camera calibration. Furthermore, the possibilities of adjusting the image pairs in postproduction are limited and time consuming.

In each step during the capture there is an opportunity for metadata collection. From this stage of the process on, it pays off to log and store as much of the metadata as possible as it becomes available during the production process: descriptions of scenes, shots, light conditions, camera positions, participants, times, costumes, and anything else that can be recorded [Cox et al., 06].

Documenting this information will pay off handsomely at the end of production. Increasingly, devices that capture pictures or sound can automatically record a good deal of the technical metadata from their own control systems—cameras that keep track of f-stop, filter wheel settings, and focal length are obvious examples. Likewise, it is becoming common for devices to capture the time of day and date and even the latitude, longitude, and altitude of their position when the recording of the clip starts. Most importantly, many modern devices generate and record a globally unique identifier for the particular clip of the material at the very instant the record button is pressed and they have the facilities to import metadata from the production office database and combine it with the output. Those technical metadata can be very important during the postproduction phase, especially if the dual camera adjustment and settings were not perfect and some minor imperfections and 3D image impairment can be corrected.

The importance of the ingestion process is emphasized by Airola, Boch and Dimino in [Airola et al., 02] and noticed that *"crucial problem of Content Management Systems (CMS) is constituted by the ingestion of new content. As we cannot realistically expect that all the aspects of a production/archive environment are under the rules of a CMS, we need to set up gateways through which the content must pass when migrating from a non-managed environment to a CMS. The role of these gateways, that we call Ingestion Systems, is that of collecting and organizing as many relevant information (metadata) on the item as possible... "*.

Ingest is the first stage in the efficient transfer of captured 3D content to the television production infrastructure. During the ingest we take all the content (both views) collected during the shooting process, as well as new metadata, and transfer it into the production environment. We assume that the planning and commissioning metadata are already in the system. More metadata can be generated at ingest and these can either be extracted automatically or entered directly, for example by an operator marking technically poor sections or regions for special processing.

Ingestion can be considered in terms of two processes or fundamental tasks [Spasic and Jankovic, 10a], [Spasic and Jankovic, 10b]:

- Content acquisition and optimization, and
- Content description and referencing.

Content acquisition and optimization imply content compression and capturing the 3D audio-video essence. Typically, the users of Content Management System will want to utilize a high resolution master file whose content is in professional broadcasting quality, as well as a low resolution proxies (also considered a meta-essence [Cox et al., 06]) of the same content for the web delivery or for searching and previewing archived material. The ingest system should provide automatic generation of high and low resolution content representations.

Standardization of the master format for 3D Home production is ongoing [Zou, 09], [Zou, 10] and the details relating to the quality of 3D video and audio as well as to technical metadata important for ingest process will be suggested.

During the content optimization the key frames should be extracted and recorded. The key frames are valuable for providing asset management solutions with representative images for browsing video, as well as for making edit decisions. The key frames should be extracted and converted to JPEG images based on the scene changes or predefined time intervals.

Logging is where the producers review what they have, and mark down the possible use of their results. If metadata logging has taken place during the shooting, this task will be much simpler and more accurate than for the material logged sometime later or after logging the legacy material.

At this stage all information necessary for producing or finding segments of 3D material must be properly structured and documented, and the missing information should be inefficient at best or prone to error at worst. Increasingly, the scene change detection and speech recognition software will be used at this stage.

2.4 Processing

The processing stage represents a craftsman work during which the 3D shots, clips, sounds and already assembled items are put into order.

The entire processed material should be regularly checked in 3D. The images that read like 2D images should be edited like 2D.

The images that have a strong 3D character need to be dealt with as 3D.

There is a variety of ways in which one can edit a stereo project. The entire editing process, which usually consists of video and audio editing, should be focused on capturing the composition metadata, the so-called Edit Decision List (EDL), in order to accurately represent the artistic composition of the program on the basis of its constituents. Typically, this results in two Edit Decision Lists, one for each eye. The inevitable items on the list were the duration of the shot and the information about the switch between one scene and the other (the "inpoint" and the "outpoint"). The list represented the switching or rendering that must be applied to the original recorded material to produce the final output. At its simplest, the EDL comprises only the switch points in terms of time codes.

Machine settings, digital effect settings, and audio mixing information should all be stored with the original recorded material if it should ever again be seamlessly used in the way it had been used before. This might happen, for example, with producing different versions, alternative cuts or, in the case of 3D production, editing the raw material for the second-eye view.

The source material might be organised with parallel directory and naming structures, so that a single EDL can be applied twice to generate the left and the right track.

Advanced effects and transitions such as fades, wipes or cross-screens should be used very carefully, because they have a different behaviour in depth. Certain editing tools offer the possibility of creating Depth Decision List (DDL), with information relating to depth editing.

With the lack of dedicated stereoscopic tools, 3D content editing is the slowest of all the postproduction phases. Mendiburu said in [Mendiburu, 09b] that *„there is an obvious conflict between the need for real-time response from the edit station and the additional overload of a stereoscopic dual stream"*. It has only recently been solved with high-end editing systems, and it is far too costly to be used by a low-budget broadcaster who wants to take time to learn and experiment on his own. This is the reason why low-budget broadcasters should choose the existing solutions to edit 3D by using regular 2D tools. A 3D editorial process for one specific platform is described in [Bellamy, 10].

Stereo sound was present in multimedia production long before 3D pictures. The new 3D sound-image space relationship has not yet been explored and discussed in open forums and conferences. Several useful observations can be found in [Mendiburu, 09b]. The first observation is that the 3D volumes do not perfectly overlap. The multichannel sound occupies the room, with left, centre and right sources right behind the screen, and one or two layers of stereophonic sources along the room length. The stereoscopic image occupies the volume designed by the comfort zone, a truncated triangle that extends a long way beyond the screen. The second observation is that the sound would not follow a 3D picture as the spectator moves from a centre seat to a side position. The third observation is that a 3D content sound mix is more of a quadriphonic mix, with emphasis on the front-to-back effects, rather than a surround mix with stereophonic voices and ambiance effects.

Different graphics, subtitling, and animations are a part of produced 3D content. Subtitles on a single screen plane of a stereoscopic content are not visually pleasing to the audience. What seems to work best is to position the subtitles slightly in front of the 3D point of interest in any given scene. This allows the audience to easily read the subtitles without refocusing.

2.5 Control

Editorial and technical acceptances, which are the constituent parts of the recurrent control stage, approve the use of the produced program material.

Technical control assumes the stereo quality control, left eye and right eye content, 3D audio and backward compatibility with 2D content devices.

If the corrections are needed, a corrective action must be undertaken until editorial and/or technical approval is received.

2.6 Archiving

The approved final product is catalogued and stored in the archive.The prime function of the archive is that it is a readily available source of material for any purpose: an authoritative source of facts and figures, research for another program, stock footage, repurposed usage of the existing material (either unseen or previously used), and even ideas and treatments.

Archiving is one of the most important and most demanding organizational and technical processes in the whole television production. Over time, media-rich organizations realized the value of their media assets. For instance, the BBC Archive system has more than 750000 hours of television programs in the archive, receives over 2000 enquires each weak and loans 45000 items per month [Evans,02]. Archival systems usually consist of different servers, such as workgroup media servers for short-term storage, and deep archive media servers for long-term storage. Among other things, archival systems can contain and manage metadata archives, low-resolution archives as well as archives of still images, effects, sounds and other media-related data. Any form of archiving requires metadata to be captured and such archiving is the prime candidate for metadata reuse, since metadata is the basis for a comprehensive search. The capture of metadata not only enhances the search, but also removes some of the overhead and uncertainty that archivists can come across in cataloguing the material. Metadata required for archiving purposes can vary depending on the particular circumstances and application and they can include identification facts (title, episode title or number, program number, tape location), technical and playout information (running time or 3D digital file format), descriptive metadata (subject, genre, summary), abbreviated production information (director, producer, cast), and initial airdate.

2.7 Publication

At some point the program will be ready for consumption and it must be prepared for distribution. For the purpose of both traditional and 3D broadcast, the correct file must be identified, scheduled, and made available to the playout system. The playout process allows for a scheduled presentation of the program produced at earlier stages. Whether live or played from the archive, the programs are sent to the delivery point (transmitter chain, web etc.).

There are many 3D content delivery combinations and possibilities. Digital terrestrial, cable and satellite broadcasting, as well as Internet streaming all have their own specific needs, usually controlled by the metadata that come with the file. Naturally, 3D TV content can be packaged and distributed off-line with already available technologies such as Blu-ray 3D™.

3 Behavioural Description of Stereoscopic 3D Content Production

The main objective of a behavioural description is to visualize how the user (represented by the actor) will interact with and use the system. This is done by showing the actor associating with one or more use cases and, additionally, by drawing many use case diagrams.

Modelling a behavioural description of stereoscopic content production will be considered in three distinct segments: preproduction, production and postproduction.

3.1 Preproduction

The main actors in the problem space of the 3D content preproduction are the producer, technical manager and archiving system. The archiving system is an actor who also plays a part in production and postproduction phases.

The use cases important for modelling in the problem space of 3D program preproduction are as follows: Research and Develop Idea, Make Storyboard and Stereopsis, Add Preproduction Metadata and Plan Logistic and Staff. Manage and Use Archives is a use case which takes part in all production phases. The Use Case diagram of program preproduction is shown in Figure 3.

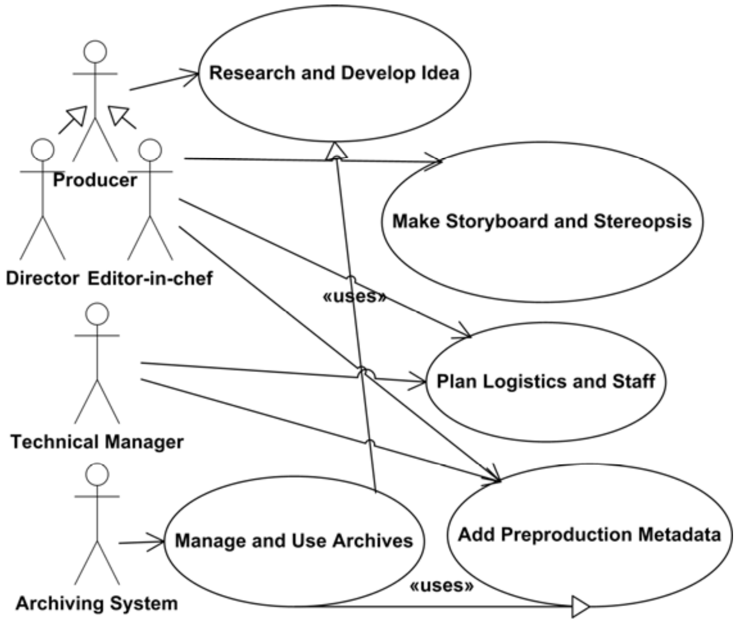

Figure 3: Use Case Diagram of 3D Preproduction

3.1.1 Use Case "Research and Develop Idea"

Short Description: The producer researches and develops an idea for the production of a 3D program item

Actors: Producer, who can be director or editor.

Pre-Conditions: New program schedule is produced and there is a need to fill the slot with 3D content.

Post-Conditions: Program ideas are investigated, commission settled, the initial script is made and the possibilities for 3D enhancements are considered.

Main Flow: (1) Producer suggests an idea for a program production. (2) Producer persuades a TV Company to finance the conversion of an idea into a real program. (3) Steps (1) to (2) are repeated until commission has been accepted (4) Research is being done, the initial script is made, the need for 3D item is analysed and Use Case terminates.

3.1.2 Use Case "Plan Logistics and Stuff"

Short Description: Managers plan the logistics and staff needed for the production of program items.

Actors: Producer, Technical manager.

Pre-Conditions: The program idea is investigated, commission settled, initial script are made and 3D needs and gains are analysed.

Post-Conditions: Production order is issued.

Main Flow: (1) Producer (Editor, Director) plans the staff needed for the production of 3D item. (2) Technical manager plans the logistics (objects, vehicles, production equipment...) necessary for the production. (3) Producer and technical manager plan the staffing. (4) Production order is being issued to all members of the production team. Use Case terminates.

3.1.3 Use Case "Make Storyboard and Stereopsis"

Short Description: Producer writes storyboard and stereopsis.

Actors: Producer.

Pre-Conditions: The program idea is investigated, commission settled, the initial script are made and 3D needs and gains are analysed. Production order is issued.

Post-Conditions: Storyboard and stereopsis are made.

Main Flow: (1) Producer (Editor, Director) defines the final storyboard based on the initial script. Producer makes stereopsis. Use Case terminates.

3.1.4 Use Case "Add Preproduction Metadata"

Short Description: Producer and technical manager add preproduction metadata.

Actors: Producer, Technical Manager.

Pre-Conditions: Production order is issued.

Post-Conditions: Preproduction metadata added.

Main Flow: (1) Producer adds metadata relating to preproduction (working title, producer's identity, possibly contributors' names, genre and scripts and stereopsis. (2) Technical Manager adds metadata relating to the equipment used in the project. Use Case terminates.

3.2 Production

The main actors in the problem space of the 3D program production are the producer, archiving system, 3D essence gathering crew (cameraman, sound recorder) and ingest operator.

The use cases important for modelling in the problem space of program production are as follows: Capture 3D Essence, Ingest 3D Essence, Add Production Metadata, Manage and Use Archives. The Use Case diagram of 3D program production phase is shown in Figure 4.

3.2.1 Use Case "Capture 3D Essence"

Short Description: 3D video shots, audio clips and other program items are being created, pre-selected, ingested into production system and logged.

Actors: Producer, Cameraman, Sound Recorder, Ingest operator.

Pre-Conditions: Production order is issued.

Post-Conditions: All essence materials, as well as relating metadata, are ingested into production system and logged.

Main Flow: (1) Cameraman prepares and adjusts the dual-camera system (2) Cameraman takes 3D shots in the studio or outdoors. (2) Sound Recorder records the sounds in the studio or outdoors (3) Producer chooses the raw material or previously produced essence from archives and repurposes it. (4) Producer reviews what he/she has, and marks down its possible use. Use Case terminates.

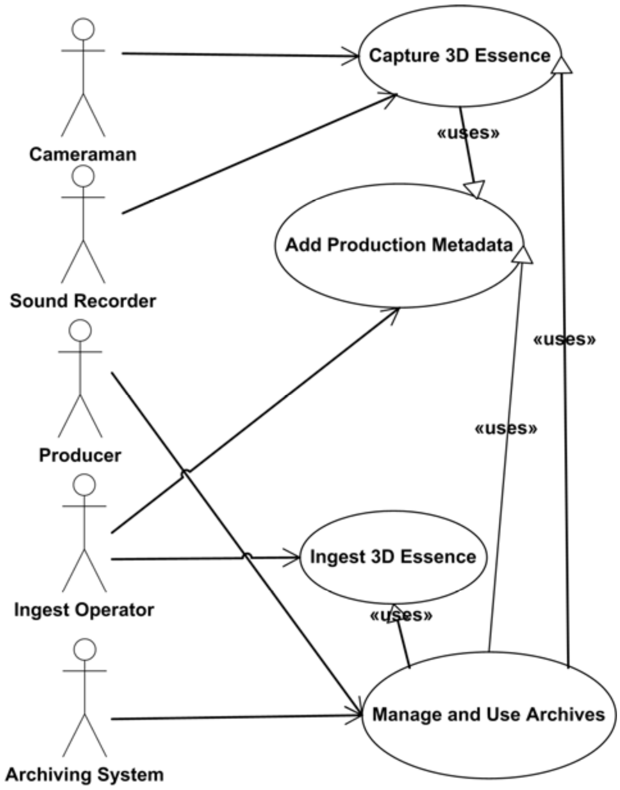

Figure 4: Use Case Diagram of 3D Production

3.2.2 Use Case “Ingest 3DEssence”

Short Description: 3D video shots, audio clips and other program items are ingested into production system.

Actors: Ingest operator.

Pre-Conditions: 3D Essence is captured.

Post-Conditions: All essence materials, as well as relating metadata, are ingested into production system.

Main Flow: (1) The entire content collected during the process of shooting, recording and repurposing is taken and transferred into the production environment. (2) Technical metadata are taken from capturing devices. Descriptive metadata are manually added. Use Case terminates.

3.2.3 Use Case “Add Production Metadata”

Short Description: Ingest operator adds production metadata.

Actors: Ingest Operator.

Pre-Conditions: 3D Essence is ingested.

Post-Conditions: Production metadata added.

Main Flow: (1) Technical metadata are taken from capturing devices. (2) Descriptive metadata are manually added. Use Case terminates.

3.2.4 Use Case “Manage and Use Archives”

Short Description: Cataloguing, storing, searching and retrieving program material to/from archives.

Actors: Archiving System.

Pre-Conditions: Approved access to archives.

Post-Conditions: Catalogued and stored essence, as well as related metadata. Essence and metadata retrieved.

Main Flow: (1) After ingestion, system catalogues and stores raw 3D essence and related metadata and supports searching and retrieving. (2) After processing and control, system catalogues and stores final 3D essence and relating metadata and supports searching and retrieving. Use Case terminates.

3.3 Postproduction

The main actors in the problem space of the 3D program postproduction are the producer, technical manager, archiving system, processing crew (video and audio editors, animator), publication system (playout and delivery subsystems), as well as the audience. The audience is the second-level actor, i.e. it is out of the boundaries of the system.

The use cases important for modelling in the problem space of program production are as follows: Edit 3D Essence, Add Postproduction Metadata, Control, Manage and Use Archives, and Publish. Use Case diagram of program production is shown in Figure 5.

3.3.1 Use Case “Edit 3D Essence”

Short Description: 3D shots, audio clips, sounds and previously assembled content items are put into order.

Actors: Video Editor, Sound Editor, Animator.

Pre-Conditions: 3D essence materials, as well as relating metadata, are ingested into production system and logged.

Post-Conditions: Essence materials, as well as relating metadata, are finalized.

Main Flow: (1) Video Editor makes corrections and adjustments to both view essences. Video Editor edits the video essence for one view and generates Edit Decision List. Video Editor applies the EDL to the second view. (2) Sound Editor edits the audio essence. (3) Animator makes the animations, graphics and subtitles in accordance with 3D rules. (4) Video Editor assembles and renders final 3D essence. (5) Use Case terminates.

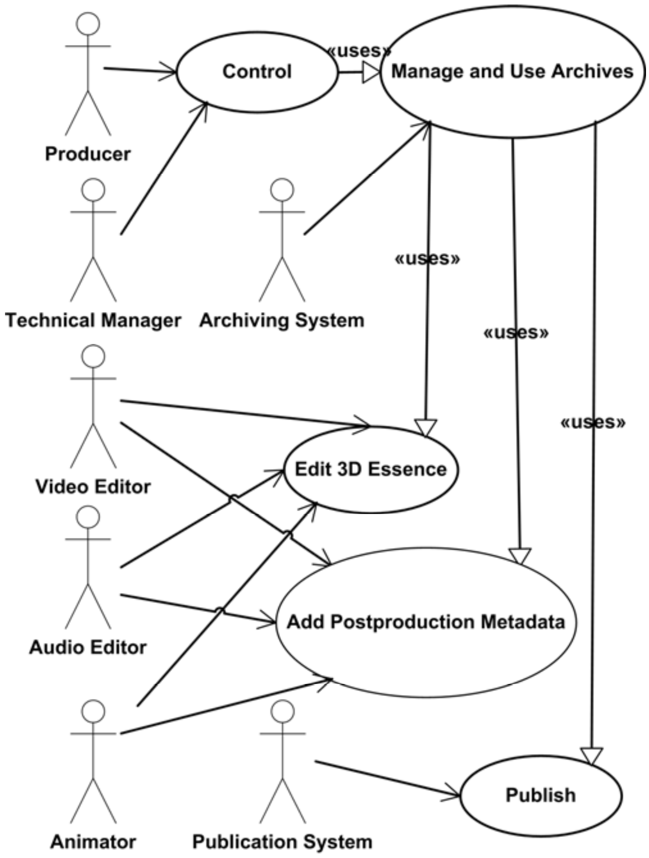

Figure 5: Use Case Diagram of 3D Postproduction

3.3.2 Use Case "Add Postproduction Metadata"

Short Description: Processing crew add descriptive metadata.
Actors: Video Editor, Sound Editor, Animator.
Pre-Conditions: 3D Essence is edited and finalized.
Post-Conditions: Postproduction metadata added.
Main Flow: (1) Descriptive metadata are manually added. Use Case terminates.

3.3.3 Use Case "Control"

Short Description: Editorial and technical acceptances approve the use of the post produced 3D program item.
Actors: Producer, Technical Manager.

Pre-Conditions: 3D essence, as well as relating metadata, is finalized.

Post-Conditions: 3D essence, as well as relating metadata, is approved. 3D content is stored in the archive.

Main Flow: (1) Editor-in-chef checks and approves or disapproves of the editorial quality of the produced material. (2) Technical Manager checks and approves or disapproves of the technical quality of the produced material. (3) If the corrections are needed, corrective actions must be undertaken [A1]. (4) Steps (1) to (3) are repeated until the produced material is accepted and Use Case terminates.

Alternate Flow: (A1) No need for corrections. Program material is approved. Use Case terminates.

3.3.4 Use Case “Publish”

Short Description: Program playout, distribution and transmission

Actors: Publication System.

Pre-Conditions: Program prepared and approved for publication.

Post-Conditions: Program transmitted/delivered.

Main Flow: (1) Program playout. (2) Program distribution. (3) Program transmission using terrestrial, cable or satellite transmission [A1]. Use Case terminates.

Alternative flow: (A1) Program delivery by means of web services. Use Case terminates.

4 Model of Stereoscopic 3D TV Content Life Cycle

The traditional emphasis of the media business has been placed on the creation, bundling and distribution of content consisting of information and entertainment.

MacRae, Craig and Bell visualized the entirety of the broadcast operations in [MacRae et al., 02]. The component planes (x axis: device, path, service, content and management services) refer to the primary means of program generation and transmission. The communication layers (y axis) relate to the standard ISO/OSI 7-layer stack with the physical layer at the bottom and high-level network applications at the top. The highest abstraction of the component plane is that of the content. This plane comprises tools that manage content in the studio and playout areas that understand physical storage for the content, perform activities such as content distribution and creation, and enable automation of the station output.

The life cycle model of 3D TV content shows the entire behaviour of the object, as it changes its state in response to the messages it receives. The nature of the state machine diagram is considered to be dynamic-behavioral. “What happens at a certain point in time?” is a question answered by the following diagram.

The state machine diagram representing the life cycle of the 3D TV content is shown in Figure 6.

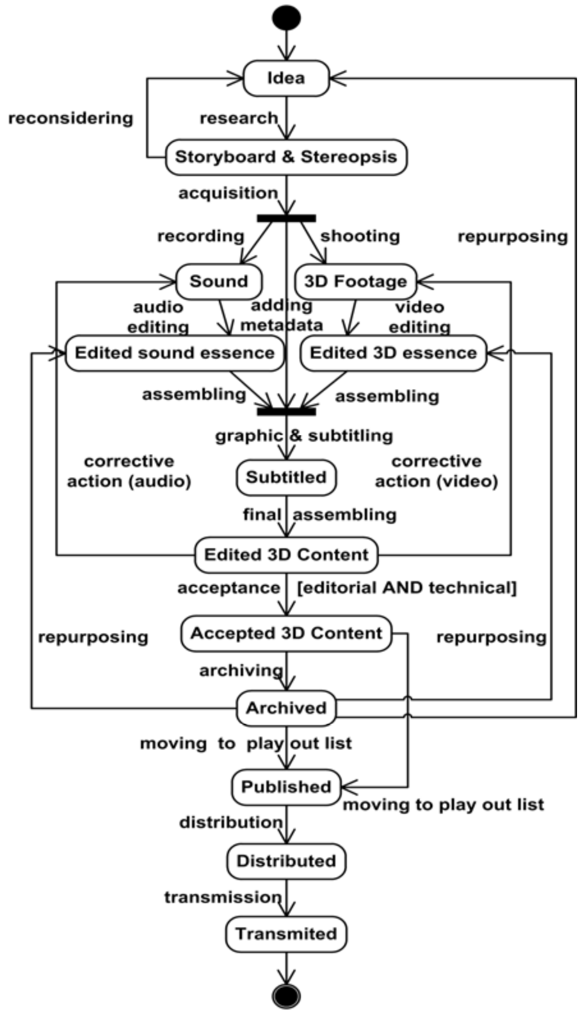

Figure 6: State Machine Diagram of 3D TV Content Life Cycle

5 Flow and Dependencies in 3D Production Process

Modelling flow of 3D production process comprises capturing activities made of smaller actions.

An action represents a single step within an activity where 3D essence processing or metadata manipulation occurs in a modelled system. Activity modelling focuses on the manner of execution and flow of the system behaviour, rather than on how it is assembled. Activity diagrams complement the use case diagrams by visually showing the internals of a use case.

Since activity diagrams show multiple threads, they can be used to optimize both business and system processes. This is because a group of processes running in parallel can be captured and modelled through multiple threads. Once they have been modelled, they can be refined and optimized. They also provide an opportunity to document not only the flow but also the role responsible for that flow.

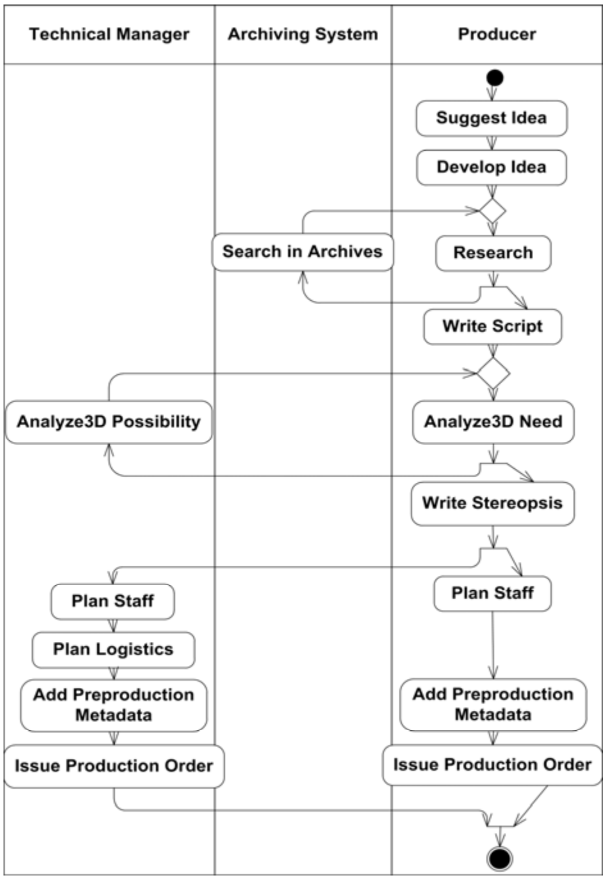

Figure 7: Activity Diagram of 3D TV Content Preproduction

Due to its complexity, the flow analysis will be divided in three consecutive parts, following the main phases in 3D programme synthesis: preproduction, production and postproduction.

The basic roles in program preproduction process are defined here as Technical Manager, Archiving System and Producer and these roles and corresponding activities are shown in Figure 7.

The basic roles in program production process are defined here as Archiving System, Producer, 3D Essence Gathering Crew and Ingest Operator, and these roles and corresponding activities are shown in Figure 8.

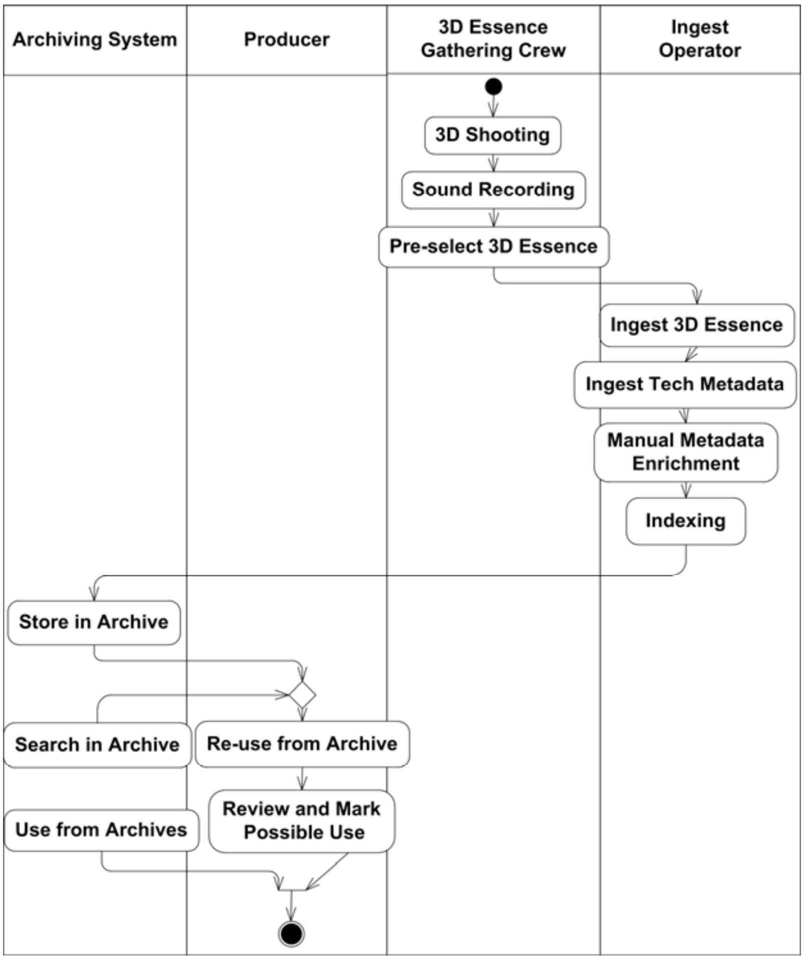

Figure 8: Activity Diagram of 3D TV Content Production

The basic roles in program postproduction process are defined here as Technical Manager, Archiving System, Producer, Processing Crew and Publication System, and these roles and corresponding activities are shown in Figure 9.

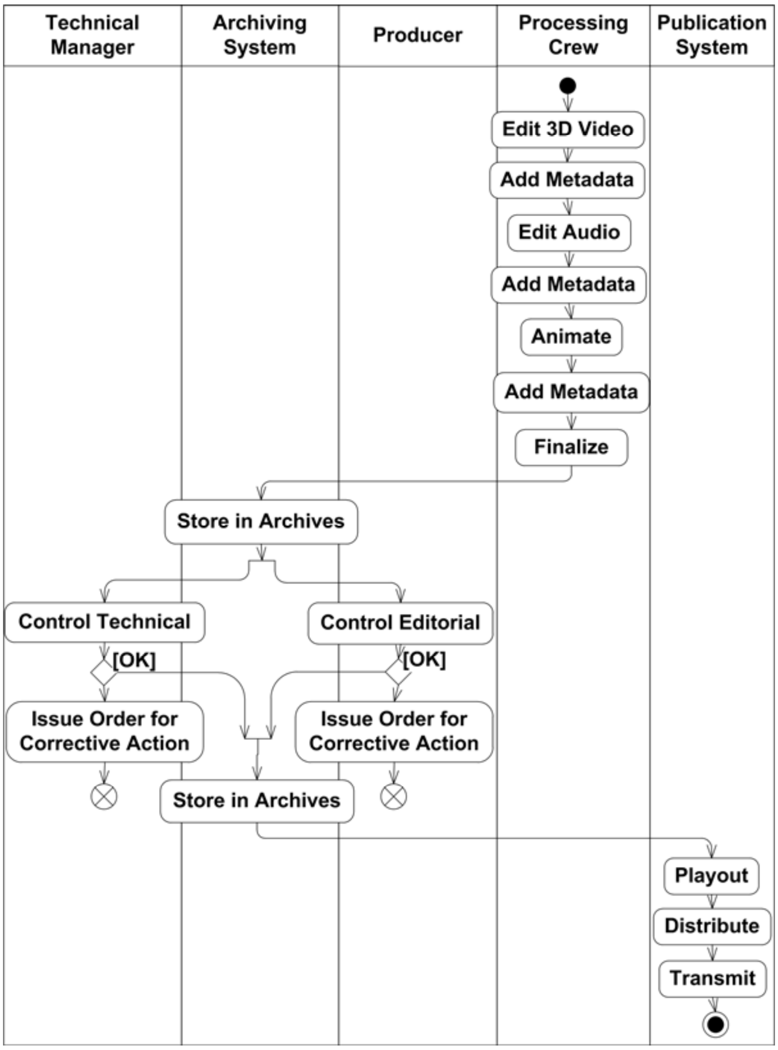

Figure 9: Activity Diagram of 3D TV Content Postproduction

6 Model of Structural Static Representation

The objective of modelling structural static representation is to represent, in one or more views, various business entities and their relationships in MOPS. Class diagrams show business-level classes as well as technical classes. In addition to showing the classes, class diagrams show the relationships between them. The entire description of the classes (or "entities," as they may be called in the problem space) and their relationships with each other are static. No dependency is shown in this diagram and no concept of time. Class diagrams, by their very nature, are very strong, structural, static representations. A class diagram of the 3D program production business process, derived from the previous analyses, is shown in Figure 10.

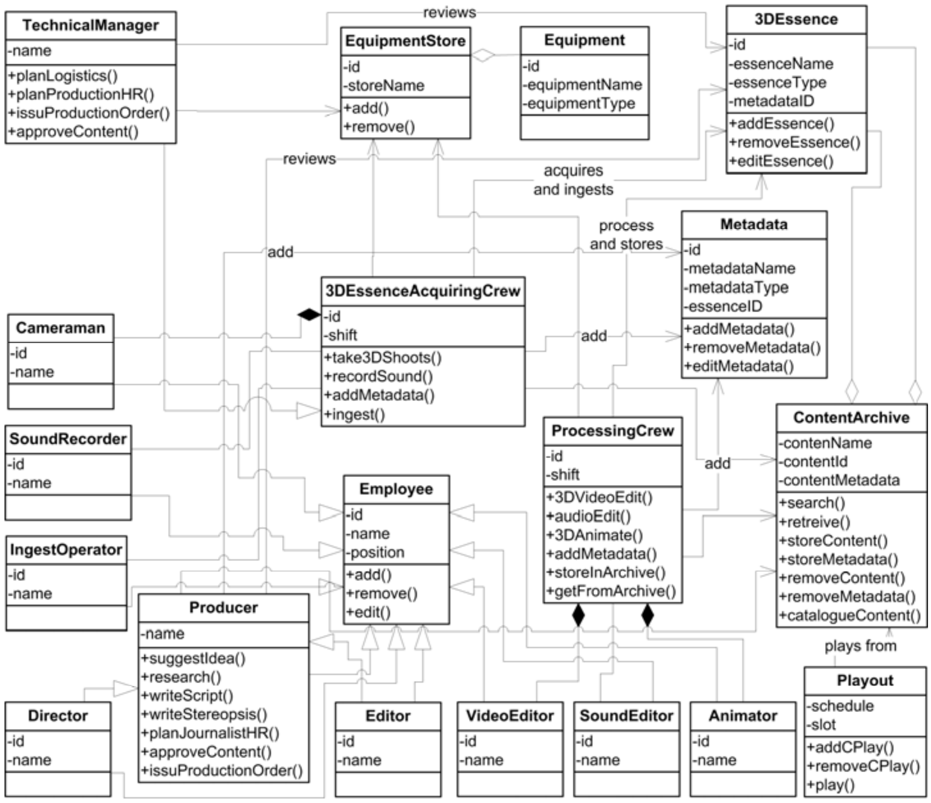

Figure10: Domain Model (Class Diagram) of 3D Programme Production

7 Conclusions

The primary aim of this paper was to motivate low-budget broadcasters to reconsider alternatives to partial in-house developments of 3D production process. To achieve this goal, broadcasters have to completely rethink the way technology can be applied to the art and business of 3D program making.

The management concepts can be applied to a wide variety of applications relating to the generation of 3D content. Therefore, the systems must be conceived with the necessary degree of flexibility. They should be required to tailor software and hardware infrastructure and functionalities, to secure the performance demanded by specific applications without incurring unjustified investments.

Three-dimensional broadcast television is believed by many to be the next logical development towards a more natural and life-like visual home entertainment experience.

It is expected that 3D content will reach homes through a variety of different channels, including packaged media such as Blu-ray 3D Disc, a cable or terrestrial broadcast, as well as Internet streaming or download. There are many obstacles in delivering 3D content to homes. It is an open question whether the delivery formats between each of these distribution channels could be harmonized, given the unique constraints associated with each of them. Another concern is reflected in the bandwidth and set-top boxes to decode and format the content for display.

Currently, and in the foreseeable future, products will be differentiated primarily by their software. As such, it is expected that software will absorb the lion’s share of the development costs. By bundling the cost of software development and support into the purchase price of the equipment, manufacturers force the users to capitalize the cost of the hardware as well as the initial and ongoing support costs of the software over the useful life of the product. This serves neither party well, as it drives up the initial costs to extremely high levels, and concurrently encourages frequent hardware turnover for the sake of supporting the software development.

As content is one of the most valuable assets for broadcasting companies, ingesting, archiving, accessing, managing, delivering and securing the content assets become one of the basic requirements in the everyday life of multimedia producers and providers. At the same time, the manner in which the company structures its facilities, the processes involved and the choice of technologies that best adhere to the purpose related to content handling becomes increasingly important.

Low-budget television broadcasters recently faced significant financial temptations during the digital turnover in broadcasting industry. It is sensible to assume that, at the moment, they are not ready to invest in new equipment necessary for the production of 3D content.

This paper describes the main areas in a 3D TV production environment and summarizes the 3D essence, metadata and control flow, as well as the main processes involved in a low-budget 3D television facility.

The first step was to describe the whole 3D TV content production chain. The second step was to propose one 3D TV production workflow. The analyses of the production stages and their integral processes helped defining the model in the problem space which is suitable for low-budget 3D TV production.

The third step in the research, which is not included in this paper, but which uses the results described here, entails developing a workflow model based on Generalized Nets (GN), instead of using some of the workflow languages, such as YAWL. YAWL (Yet Another Workflow Language) is a formal language developed around the state-transition systems based on Petri nets, with the purpose of defining control procedures in a workflow management. In the same context of other workflow languages such as the Business Process Execution Language (BPEL) or scientific workflow languages such as Simple Conceptual Unified Flow Language (SCUFL) YAWL is a model definition language that can be executed on the YAWL engine.

Generalized Nets is a concept extending the concept of Petri nets and the rest of its modifications. One of the aspects of generalization is the fact that the GN transitions possess an index matrix of predicates, determining the conditions for tokens' transfer from any input to any output place of the transition. On the other hand, the tokens enter the GN with their initial characteristics and during their transfer from the input to the output places of transition they are assigned new characteristics by means of special characteristic functions. The proposed GN model, which consists of 11 transitions and 75 places, can be exported in XML format and one XGN (XML GN) model is presented in [Spasic, 13].

Modelling in the problem space is used as a research method in this paper and the first step in modelling of software intensive 3D television production is presented here.

The current work demonstrates that the UML provides an extensive set of tools to describe the production of the 3D TV content, as well the business model of the 3D TV production. A business analysis of the problem space and behavioural description of a 3D content workflow is done by using the use case diagrams. The life cycle of stereoscopic 3D content is defined by state machine diagram and flow and dependencies are analysed by using activity diagrams for preproduction, production and postproduction phases. Model of structural static representation is proposed and defined by a class diagram.

The challenge for the future is to make the model of solution space, as well as the model of background space of the 3D television production.

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