Continuously Adjustable Pulfrich Spectacles for Mobile Devices

Ken Jacobs, Binghamton University, Binghamton NY
Ron Karpf, ADDIS Incorporated, Corvallis OR

This is a draft of the paper to be presented at the The IS&T/SPIE Electronic Imaging Multimedia on Mobile Devices Conference. The Conference will be held at the Hyatt Regency San Francisco Airport Hotel Monday - Wednesday, January 24 - 25, 2012.

The paper "Continuously Adjustable Pulfrich Spectacles for Mobile Devices" will be included in the conference proceedings.

Copyright 2012, Society of Photo-Optical Instrumentation Engineers. One print or electronic copy may be made for personal use only. Systematic electronic or print reproduction and distribution, duplication of any material in this paper for a fee or for commercial purposes, or modification of the content of the paper are prohibited.
Continuously Adjustable Pulfrich Spectacles for Mobile Devices
Ken Jacobsα, Binghamton University, Binghamton NY
Ron Karpfβ, ADDIS Incorporated, Corvallis OR

ABSTRACT

Mobile devices present a challenging platform for 3D video because of inherent device limitations. Continuously Adjustable Pulfrich Spectacles for Mobile Devices (CAPS-MD) is a new implementation of the Pulfrich 3D stereoscopic effect. For every scene that contains lateral motion in a 2D movie, CAPS-MD provides realistic 3D. Since it requires minimal additional processing, it is appropriate for mobile devices.

3D movies utilizing the Pulfrich stereoscopic effect have been made for 80 years using passive viewing spectacles. CAPS-MD use active viewing spectacles to overcome the limitations of passive spectacles. 3D movies normally employ the asymmetry of dual images to produce stereopsis. CAPS-MD works on the principle of illumination asymmetry, and only needs to control the differential lens optical densities.

CAPS-MD is fabricated from optoelectronic materials that electronically control the lens optical densities. The eye’s retinal triggering is used by CAPS-MD to determine the differential lens optical densities. Motion estimation calculations from the digital image processing used to display 2D video on mobile devices are reused to calculate real-time lens adjustments so CAPS-MD always conform to the optical density that optimizes the Pulfrich stereoscopic effect. Only negligible additional processing is necessary for CAPS-MD to show 3D for every scene that contains lateral motion in any 2D movie.

Keywords: Pulfrich effect, Continuously Adjustable Pulfrich Spectacles, Mobile devices, Translational research

1. INTRODUCTION

Mobile devices present a challenging platform for 3D video due to their inherent device limitations. These limitations are well known. Bandwidth constrains today’s most reliable 4G systems. 3D video is processing intensive, consuming the fixed power and processing resources of mobile devices. 3D autostereoscopic screens add to the complexity and device costs of mobile devices, and consume more of their fixed limited resources.

Video on mobile devices is inherently a single-user system, so the industry is focused on autostereoscopic display screens for viewing 3D video. However, dual-image 3D content halves the resolution of delivered content. This increases the costs and complexity of mobile devices and requires higher resolution viewing screens as well as new 3D formats and applications. Autostereoscopic displays have their own cost, implementation and manufacturing problems. Also, Digital Rights Management (DRM) is more difficult to implement as consumers of video on mobile devices expect reasonable sharing privileges for purchased content. And, for the foreseeable future, there will continue to be a dearth of 3D content.

Continuously Adjustable Pulfrich Spectacles for Mobile Devices (CAPS-MD) is a new implementation of the Pulfrich stereophenomenon that addresses many of these problems. Pulfrich 3D is a single-image 3D solution fully consistent with 2D viewing. In its essence, CAPS-MD is Time Shift 3D. While one eye views the current video frame, the other eye (viewing the video through a darkened lens) views an earlier frame of video. In the presence of motion, the mind fuses these slightly disparate images into 3D. While CAPS-MD requires the user to wear special 3D viewing spectacles, and the 3D is limited to scenes that have lateral motion, they allow the user to view all 2D video content in 3D. This has significant benefit to the viewer, content provider, mobile device manufacturer and cell-phone company.

For the content provider, no special preparation or processing is required to record or adapt content. By wearing CAPS-MD, all 2D content is embellished allowing intermittent 3D viewing for those scenes containing motion. For the mobile Device Manufacturer, CAPS-MD provides a new 3D option – that is easy and straightforward to implement.

α nervousKen@aol.com Ken’s email address is a reference to his nervous system performances using double analysis-projector set-up for deriving 3D from standard 2D film.
β rsk@the4dgroup.com
CAPS-MD reuses processing and communication features already widely implemented in mobile devices. The processing of motion vectors already performed in the mobile devices’ System on a Chip (SoC) is reused to calculate the correct lens optical density. Bluetooth connectivity is used for control of the 3D viewing spectacle by the Mobile Device. Since CAPS-MD works with any mobile display technology and can be implemented with any mobile display technology, it is less costly than those with autostereoscopic screens.

For the cell-phone companies, CAPS-MD works within the existing distribution methods for mobile content delivery. No new formats or standards are needed to view 2D video as 3D. Existing means of distribution of 2D video are reused that allow the user to view any video in 3D while wearing CAPS-MD. Today, viewers of video on mobile devices are hungry for 3D content. With CAPS-MD there is no lack of content, since all 2D content is simultaneously 3D content.

2. BACKGROUND

Lenny Lipton, in his 1982 seminal text “Foundations of the Stereoscopic Cinema,” talked about independent filmmakers that work in the stereoscopic medium and noted “Ken Jacobs has . . . exploited the Pulfrich phenomenon by equipping audience members with neutral-density monocles.” The Pulfrich phenomenon was first identified about 90 years ago. Using passive spectacles with a fixed dark lens, it has been the basis for a number of 3D movies. CAPS-MD is a new active spectacle implementation of the Pulfrich phenomenon that greatly expands its usefulness as a technique for 3D movies.

Pulfrich 3D has been used in production of such movies as the 1971 feature length movie “I, Monster” starring Christopher Lee; in 1989 for the first live 3D TV broadcast of the Tournament of the Roses Centennial Parade on the Fox Network; in 1989 for the first live Superbowl (XXIII) half-time show; for the 1990 videos “Steel Wheels” Rolling Stones tour” with segments of the videos broadcast by FOX as part of a prime-time Rolling Stones; for the 1997 second season finale of the network TV sitcom “Third Rock From The Sun”; for episodes of the Discovery Channel’s “Shark Week” in 2000; for the 1993 Doctor Who charity special “Dimensions in Time”; an episode of “Power Rangers”; segments of the animated programs “The Bots Master” and “Space Strikers”; “Howard Stern's Butt Bongo Fiesta” in 1992; the videogame “Org-3D”; and “Lost Dimension in 3D” for the Super Nintendo gaming system. The feature length 3D movie “Future Fighters”, now scheduled for release in 2014, uses Pulfrich 3D.

Figure 1: A 3D frame from the Mulholland Drive video
3D motion picture stereoscopy requires that each eye see a separate, slightly offset view of a scene. Normally, this is achieved by filming and projecting stereo pairs or dual images – one image being sent to each eye. Figure 1 shows a single frame from a 3D movie with dual images in a side-by-side format. While 3D movies typically use the asymmetry of dual images to produce stereopsis, all that Pulfrich 3D requires to view movies in depth is an illumination asymmetry caused by a controlled difference in optical density between the lenses.

With the Pulfrich phenomenon, a darkened neutral density filter is introduced in front of one eye – delaying its visual message. A viewer focusing on the single-image of a 2D movie will see, in effect, a stereo pair of past and present images: the actual image on-screen and the image that had been seen on-screen a moment before. This creates parallel perspectives for the mind to construct depth from even the slightest lateral shift movement in a sequence of frames. These somewhat contradictory images are resolved in the mind as if they are two simultaneous perspectives by using the same method it normally uses to provide the appearance of depth from two 2D perspectives.

As an example, Figure 2 shows a sequence of three successive frames from a 2D version of the Mulholland Drive video. In this scene the movement is from left-to-right. With Pulfrich 3D, if a darkened neutral filter is placed before the right-eye, the visual message to that eye is delayed so it sees an earlier frame. While the left-eye views the current frame (Frame n+2) through a clear lens, the visual message from the right-eye through the darkened filter is delayed and the right-eye sees an earlier frame. The degree of darkness for the filter over the right-eye determines which of the previous frame images is used to make up the stereo pair.

![Frames from 2-D Video](image)

Figure 2: Successive frames from the 2D Mulholland Drive video

The standard implementation of Pulfrich 3D uses passive spectacles with one fixed lens neutral-dark, and the other fixed lens clear. Wearing passive Pulfrich spectacles, the right-eye would see the current image, and the left-eye would see a previous delayed frame. We refer to this as ‘viewing with frame-delay’ or just ‘frame-delay’. With passive spectacles the ‘frame-delay’ is constant, unchanging, and uncontrolled throughout the movie. This is problematical. In a regular movie, screen motion changes direction and speed, so with the constant ‘frame-delay’ of Pulfrich passive spectacles, screen parallax continually switches between positive and negative with changing depth magnitude. Pulfrich 3D movies control these problems by severely limiting screen motion, and conventionally made Pulfrich 3D movies have constant lateral speed in a single direction.

---

Figure 1: This frame is taken from the Mulholland Drive video filmed by FireLineStudios (http://firelinestudios.com/) and posted on YouTube (http://www.youtube.com/watch?v=JucU0or9I64)
2.1 Continuously Adjustable Pulfrich Spectacles for Mobile Devices (CAPS-MD)

CAPS-MD is a new implementation of Pulfrich 3D that uses active rather than passive spectacles. Active spectacles overcome the problem of constant ‘frame-delay’ of passive Pulfrich spectacles by modulating the darkness of the lenses. CAPS-MD changes lens darkness, adjusting to motion and light in the movie. Rather than limiting the scenes of a movie as required with passive spectacles, CAPS-MD adjusts the lens optical density on a frame-by-frame basis synchronized to motion in the movie to optimize the Pulfrich stereo phenomenon. We can explain this using Figures 1 and 2.

Figure 1 shows a single frame of a 3D video in side-by-side format. A spectacle selection device is used so that the viewer’s right-eye sees the right-eye image and the viewer’s left-eye sees the left-eye image. Note that Figure 2 has frames of the 2D video that are similar to the side-by-side pairs in the 3D frame. In Figure 2, ‘Frame n+2’ is similar to the left-eye image of Figure 1, and the earlier ‘Frame n’ is similar to the right-eye image. CAPS-MD sets the darkness of its right lens so that the right-eye sees ‘Frame n’ and the left-eye sees ‘Frame n+2’. With CAPS-MD, we ‘optimize the Pulfrich stereo phenomenon’ by setting the darkness of the CAPS-MD lenses so the viewer is always presented with the set of dual-images from a 2D movie most similar to those in a 3D version of the movie. This provides the viewer with the same sense of depth from the sequence of 2D frames as from the 3D movie. CAPS-MD modulates the lens darkness throughout the movie on a frame-by-frame basis so the viewer always sees the best pair of 2D frames for 3D viewing. To a viewer, all passages of 2D Avatar for which CAPS-MD can generate the correct stereo pairs would similarly be indistinguishable from 3D Avatar.

‘Frame-delay’ is not a new method for 2D-to-3D conversion. What is new with CAPS-MD is:

- CAPS-MD continuously modulates the ‘frame-delay’ using a constantly changing illumination asymmetry so the viewer sees the best stereo pairs, and;
- CAPS-MD only needs the motion vectors already calculated during digital image-processing to identify the best stereo pairs.

This has substantial benefits to the viewer of video on mobile devices. CAPS-MD is an intermittent\(^6\) 3D enhancement to 2D viewing. Only those passages that can be converted are shown to the viewer in 3D. All other scenes appear in 2D. A viewer can opt-in and wear CAPS-MD for intermittent 3D viewing, or opt-out, removing CAPS-MD, and view the video in 2D.

It also has substantial benefit to the Mobile Device industry. CAPS-MD shows 2D movies in 3D without change to the video architecture and infrastructure; without additional production or exhibition cost, and with no requirement for 3D cameras, 3D digital formats, or 3D projectors. CAPS-MD works with all digital video content, by any mode of transmission, and for projection screens, digital or analogue monitors. Most importantly, CAPS-MD is easy to implement since it re-uses results from the intensive image-processing necessary for digital video.

We now describe the CAPS-MD lens calculation and the mobile device components used to build CAPS-MD.

2.2 CAPS-MD Lens Calculations Using Retinal Delay

Retinal Reaction Time curve

It is natural to assume that our eyes continuously send visual stimulation to our brain – but that is not the case. While more than 100 million visual receptors in each eye are ‘continuously’ stimulated, each retina triggers at ‘discrete’ time intervals sending visual information to the brain. The triggering is faster with brighter retinal illumination and slower with darker retinal illumination.

The eye’s retinal triggering mechanism has been well studied and documented in the scientific fields of visual perception, neurocinematics, psychology, optics, and ophthalmology\(^3 \text{,} 4 \text{,} 5 \text{,} 6\). Figure 3 shows the retinal reaction time under various lighting conditions\(^\varepsilon\). As an example, with light approximating that of a “Grey sky at noon,” the retinal reaction time is about 100 msec while for light approximating a “Night sky with a full moon”, the retinal reaction time is about 300 msec.

\(^{\varepsilon}\) Francis Ford Coppola’s first 3D film, “Twixt,” which premiered at the Toronto Film Festival, uses intermittent 3D. Many other dual-image 3D movies use intermittent 3D.

\(^{\varepsilon}\) The retinal reaction curve of Figure 3 was derived from the referenced work of A. Lit.
By differentially controlling the retinal reaction time of each eye, the illusion of depth can be created from sequential frames in a video. If one eye views a movie through a clear lens in a room with ambient light that has the brightness of a “Grey sky at noon” and the other eye views the movie through a neutral dark lens simulating light of a “Night sky with a full moon” the difference in Retinal Reaction time between the two eyes is 200 milliseconds. For this example, on a standard video at 30 fps, the brain will perceive images that are offset by 6 frames of video.

Controlling the Pulfrich Effect

Using the Retinal Reaction Time curve, an objective function can be calculated to set the optical density (OD) of the shaded eye that is based on (1) the retinal illumination of the clear or unshaded eye, and (2) the motion vector of a focal object. For instance, a reasonable objective function sets the OD of the shaded lens by selecting an OD for the motion-directed eye so the eye-brain perceives the lagging image at a distance from the instant image equal to the average interpupillary distance. For such an objective function, the dual images from corresponding left-image and right-image points subtend the same angle to the viewer’s eyes as with normal stereopsis. The viewer perceives the 2D movie with realistic depth. In general, an objective function should be chosen to achieve orthoscopy – a depth-enhanced viewing “appearing exactly like the real object or scene at the time of photography.”

All scenes containing motion in any video would appear in 3D, including scenes with slow to fast motion in either direction, and over a range of lighting conditions from bright to dark. As long as there is screen movement, CAPS-MD can provide the two stereo pairs appropriate for perceiving a scene in depth. Identifying the two optimal images is a complex computer-intensive image-processing problem. Digital image-processing is already extensively implemented as solutions to unrelated problems in the fields of digital video. By leveraging those solutions, CAPS-MD can synchronize every instance of screen motion on a frame-by-frame basis in real-time so the movie views with pronounced dimensionality.

Calculating Screen Parallax for the Mulholland Drive Video

Screen parallax using CAPS-MD is dependent on the illumination asymmetry between the lenses of the spectacles. Faster screen motion requires less illumination asymmetry; slower screen motion requires more illumination asymmetry. The Mulholland Drive video has fast foreground lateral motion with a central focal object traversing the screen from left-to-right in about 2 seconds. For the central focal object to move 2½ inches in object space, the retinal illumination
of the motion-directed eye will be set so the lagging image is perceived 2 frames from the instant image. At 30 fps, that is a difference of no more than 66 msec.

Since the direction of screen motion in this film clip is left-to-right, the ‘clear’ lens is configured to control retinal illumination in front of the left-eye. On a frame-by-frame basis, CAPS-MD modulates the transparency of the lens before the right-eye. If the screen traverse time of a central focal object in a frame is about 2 seconds, the darker lens in front of the motion directed right-eye is set so it produces a retinal delay that is 66 msec slower than the right-eye. If the video is viewed in light approximating that of a clear sky, the retinal delay of the clear left eye is about 200 msecs. We then set the optical density of the right lens of CAPS-MD so the right eye has a retinal delay of 266 msecs. With this illumination asymmetry, the eye-brain perceives a lagging image 2 frames before the instant image. This produces negative screen parallax and realistic stereopsis so the 2D Mulholland Drive video is seen in 3D, and CAPS-MD provides the viewer with 3D comparable to that in its dual-image 3D movie.

3. CAPS-MD 3D VIEWING SPECTACLES USING OPTOELECTRONIC LENSES

Optoelectronics is an enabling technology for CAPS-MD 3D viewing spectacles. Electronics materials respond reliably and predictably to the application of a voltage potential, and materials that change color and light transmittance in response to a voltage potential have long been known. The scientific field of optoelectronics has studied and catalogued materials that respond to the application of an electronic potential by changing its optical density. Electrochromic material can be used to fabricate the CAPS-MD, though other optoelectronic materials could similarly be used.

Electrochromics devices have been used for self-darkening rear-view mirrors, windows to reduce buildings’ energy costs, controllable windows in newer model Boeing planes, and motorcycle helmets. Infrared electrochromics have been tested for USAF jet pilot helmets. Electrochromic sunglasses have electronically controlled lenses, with the right and left lenses assuming the same darkened state. CAPS-MD spectacles can be built using such optoelectronic materials with a microprocessor controlling variable darkening for each individual lens.

For every other 3D spectacle system, it is sufficient to interpose lenses or a barrier between the eyes and the viewing screen. However, CAPS-MD depends on controlling retinal illumination that includes not only light energy emitting from the picture, but also other light sources such as ambient light. CAPS-MD spectacle design must account for all sources of retinal illumination.

The Pulfrich stereophenomenon was first identified in 1922. Also in 1922, the Eclipse method of mechanical shutters was used commercially for the first and only time at the Selwyn Theater in New York. The Eclipse system (1922) “... uses motorized shutters in spectacle frames rotating in synchronization with the projector shutter.” 3D using shuttering was then forgotten for half a century.

However, old ideas may have a new life when rejuvenated with technology. In the mid-1970s mechanical shutters were replaced with optoelectronic LCD lenses and electronic synchronization resulting in the widely used Active Shutter Glasses method for 3D. Similarly with CAPS-MD – we are proposing to rejuvenate passive Pulfrich 3D by applying technology to remove its limitations. CAPS-MD uses optoelectronic lenses, microprocessors, and the motion vectors already calculated for digital cinema to provide a better implementation of Pulfrich 3D that has 3D potential for the industry and viewers.

4. SYNCHRONIZATION OF CAPS-MD VIEWING SPECTACLES WITH THE MOVIE

Real-time synchronization between the movie and CAPS-MD requires frame-by-frame control of the optical density of the optoelectronic lenses to maximize the Pulfrich stereo effect. For the last 60 years, video engineers have worked on

---

6 Electrochromism is the phenomenon displayed by some chemicals of reversibly changing color when an electric potential is applied. Electrochromism has a history dating back to the nineteenth century and there are thousands of chemical systems that have already been identified as electrochromic. Other materials that reversibly change color when an electric potential is applied include suspended particle devices, polymer dispersed liquid crystal devices, and SmartGlass.

7 Several companies have already developed and marketed electrochromic sunglasses. In 1993 Nikon produced Selspeed, the world's first electrochromic sunglasses, with lenses that changed in response to brightness. In the film “Mission Impossible” Tom Cruise wore one of only three pairs of Nikon Selspeed electrochromic sunglasses still available in Europe. Other companies have also created electrochromic sunglasses, but in each case have failed commercially.
the problems of de-interlacing, up-conversion, and digital video compression and decompression. The intensive image-processing algorithms that are key to the solution of these digital cinema problems also process change information between frames, and store and use motion vectors. CAPS-MD reuses these well-researched and implemented comprehensive image-processing solutions to ‘optimize the Pulfrich stereo phenomenon’. Without the re-use of these image-processing algorithms, real-time CAPS-MD would not be possible.

Figure 4 summarizes the impressive body of image-processing solutions that enable on-the-fly, real-time synchronization between any movie and CAPS-MD. Uncompressed, a 2-hour TV Broadcast quality video is about 194 Gbytes, or 42 DVDs 10. Without the computationally intensive image-processing developed by the industry over the last 60-years and used for up-conversion, de-interlacing, and video compression, digital video would not be possible.

CAPS-MD re-uses this image-processing to calculate a Characteristic Motion Vector (CMV) that summarizes lateral motion between frames of a movie. The CMV is used to optimize the optical densities of the spectacles. Depending upon the nature of the digital file, different algorithms may be employed to calculate the CMV. For instance, if an MPEG-4 digital file contains good coding of ‘sprites’, it may be sufficient to calculate the CMV from the sprites motion vectors. In general, however, two region-based methods for developing on-the-fly, real-time synchronization between a digital movie and CAPS-MD 3D viewing spectacles can be used.

4.1 Software-based CAPS-MD Synchronization

Synchronization between a video and CAPS-MD can be developed directly from information already calculated and contained in a compressed digital video file. With burgeoning demand for motion video, bandwidth is a limited and precious commodity. To minimize bandwidth, digital video compression is utilized. Since the background for any given scene changes little between frames and, further, since that same background also redundantly appears in temporally related video frames, digital video compression relies on identifying, quantifying and recording ‘temporal redundancies’ or those areas of a frame of digitized video that are identical from frame-to-frame.

Consider the widely used MPEG 11 digital compression techniques, a standard for recording and distributing digital video. In MPEG compression, a frame of video is organized as 8x8-pixel macroblocks. MPEG records not just background macro-blocks that do not move but the motion of macro-blocks as they move between frames, with as much as 64 pixel horizontal and vertical offset or displacement between frames. These motion vectors are encoded in the compressed video bit-stream as (x,y) or (horizontal, vertical) pairs of integers taking values from –64 to +64 indicating movement of the associated macro-block left and right, or up and down.

These calculated motion vectors can, in turn, be used by CAPS-MD to calculate the speed and direction of motion that characterizes each frame of video in a motion picture. That is, the CMV is just a summary statistic (weighted average)
calculated from the motion vectors. No intensive video processing is required to produce the CAPS-MD synchronization signals – only a simple calculation from the already calculated motion vectors in the MPEG video stream.

### 4.2 Hardware-based CAPS-MD Synchronization

Real-time synchronization between a video and CAPS-MD can be developed directly from information calculated by a digital Video Format Conversion Chip. To maximize picture quality, motion vectors must be calculated in real-time by the Video Format Conversion Chips that are in every Digital TV and Digital Projector. These motion vectors are sufficient to calculate the CAPS-MD synchronization signals. While the calculation of these motion vectors is a complex and computer intensive process, the use of already-calculated motion vectors to synchronize spectacles to the motion video in real-time is simple and straightforward.

Two of the problems addressed by the field of digital Video Format Conversion Chips are de-interlacing and up-conversion. Consider the following simplified example. The movie “The Wizard Of Oz” was filmed at 24 frames per second, but when shown on Cable TV, it will be viewed by customers with older interlaced TV using the NTSC format, as well as with newer non-interlaced HiDef digital LCD TV that have a refresh rate of 100 Hz. Where do all those extra video frames for a 100Hz non-interlaced TV come from, without distorting and introducing motion artifacts? In our example, when the “Wizard Of Oz” is broadcast for general viewing, the TV may be required to generate 3 new frames of video for each single frame of broadcast video.

Creating these extra frames in real-time is achieved using a digital technique known as ‘Motion Compensation.’ Motion Compensation is implemented by tracking motion between frames for small blocks of pixels, requiring complex real-time image-processing to construct the new frames of video. The motion vectors calculated to implement ‘Motion Compensation’ can in turn be used by CAPS-MD to calculate the speed and direction of motion that characterize each frame of video in a motion picture. That is, the CMV is just a summary statistic (weighted average) calculated from the ‘Motion Compensation’ motion vectors. No intensive image-processing is required to produce the synchronization signals – only a simple calculation from the motion vectors that are already calculated and stored by the video format conversion chips.

### 5. CONTROL SIGNALIZATION FOR CAPS-MD VIEWING SPECTACLES

Once the CAPS-MD synchronization signals are calculated, they are then used to control CAPS-MD 3D viewing spectacles. Continuous control is provided on a frame-by-frame basis so the CAPS-MD viewing spectacles are perfectly synchronized to the movie to always take the optical density state that maximizes the Pulfrich effect. Even if CAPS-MD viewing spectacles are fabricated from a material that changes state slowly, they are optimal in the sense that they are ‘continuously adjusting’ to the optimal state.
Communication of the synchronization signals can be via any wired or wireless means available on the Mobile Device. The data synchronization requirement is minimal – about 200 bytes/second. Preferably, the synchronization signals – the calculated lens optical densities – are transmitted using Bluetooth technology that is now standard on most mobile devices.

Figure 5 shows a typical implementation of CAPS-MD on a mobile device. Video-In is streamed to the Mobile Device over a wireless telephone or Wifi connection. The video is decoded by the SoC based hardware Codec that displays the audio/video output of the movie to the viewer. At the same time, the Codec processes the motion vectors included in the video compressed bit stream and calculates the CAPS-MD synchronization signals. These signals control the CAPS-Mobile viewing spectacles, allowing scenes with motion in a 2D movie to be viewed in 3D.

6. AN APPLICATION

A CAPS-MD system for streaming video can be built by processing the digital video files on the mobile device. The optimal synchronization signals to control CAPS-MD 3D viewing spectacles are calculated during the video decompression on the mobile device from the temporal redundancy motion information coded into the compressed video.

Figure 6 shows a live 2D football broadcast being viewed in 3D on a mobile device.

![Image](image)

Figure 6: A live 2D football broadcast viewed in 3D on a mobile device

The live 2D football broadcast is streamed to the mobile device and viewed on a 2D screen. During decompression of the live sports broadcast on the mobile device, the CAPS-MD synchronization signals are calculated. The synchronization signals are then transmitted to CAPS-MD using the Bluetooth feature of the mobile device. These signals are sufficient to control the CAPS-MD viewing spectacles so that the viewer may view action scenes in 3D.

With this straightforward implementation, all scenes of the live 2D football broadcast streamed over the Internet can be viewed in 3D while wearing CAPS-MD 3D viewing spectacles. If the movies are viewed without spectacles, then they appear in 2D. No changes to the movie, means of distribution, video formats, or viewing monitors are required.

7. CONCLUSIONS

We have described CAPS-MD for viewing 3D from ordinary 2D transmissions on a mobile device. The spectacles are built using microprocessor controlled optoelectronic lenses with Bluetooth connectivity to the mobile device. The optical density of the lenses is set on a frame-by-frame basis. The optimal lens calculations re-use the motion vectors already calculated as solutions to other digital video problems, so the calculations are not computer intensive. This approach has substantial benefits over other dual-image means for 3D.
For the viewer, CAPS-MD is an intermittent 3D enhancement to 2D viewing. Only those scenes that can be converted are shown to the viewer in 3D. All other scenes appear in 2D. Any viewer can put on CAPS-MD for 3D viewing of a 2D movie, or remove them and view in 2D. All 2D content is thus intermittently viewable in 3D. Implementation of CAPS-MD re-uses results from the intensive image-processing necessary for digital video.

For the mobile device industry, CAPS-MD shows every 2D movies in 3D without change to the video architecture or infrastructure. This is achieved without additional production or exhibition cost and no requirement for 3D cameras, 3D digital formats, or 3D projectors.

8. ACKNOWLEDGEMENTS
We would like to thank Mark Seiler for his assistance.

9. REFERENCES
[10] Iain Richardson, [Video Codec Design], John Wiley and Sons, 2002